STATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

AQUATICS RESOURCES INJURY ASSESSMENT REPORT
UPPER CLARK FORK RIVER BASIN

JANUARY 1995

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INJURY ASSESSMENT REPORT

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Prepared by:

RCG/Hagler Bailly
P.O. Drawer O
Boulder, CO 80306-1906
(303) 449-5515

Primary Authors:

Joshua Lipton, Ph.D., Project Manager
Doug Beltman, RCG/Hagler Bailly
Harold Bergman, Ph.D., University of Wyoming
Don Chapman, Ph.D., Don Chapman Consultants, Inc.
Tracy Hillman, Ph.D., Don Chapman Consultants, Inc.
Mark Kerr, Montana Natural Resource Damage Litigation Program
Johnnie Moore, Ph.D., University of Montana
Dan Woodward, National Biological Survey

Contributing Authors:

David Cacela, RCG/Hagler Bailly
Aida Farag, Ph.D., National Biological Survey
Tim Hardin, Hardin-Davis, Inc.
Sherman Jensen, White Horse Associates, Inc.
Ann Maest, Ph.D., RCG/Hagler Bailly
John Marr, Ph.D., RCG/Hagler Bailly
Lyman McDonald, Ph.D., WEST, Inc.
Glenn Phillips, Ph.D., Montana Department of Fish, Wildlife, and Parks
William Platts, Ph.D., Don Chapman Consultants, Inc.

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(303) 449-5515

It is anticipated that the following contributors will testify as expert witnesses:

Doug Beltman, RCG/Hagler Bailly
Harold Bergman, Ph.D., University of Wyoming
Don Chapman, Ph.D., Don Chapman Consultants, Inc.
Tim Hardin, Hardin-Davis, Inc.
Tracy Hillman, Ph.D., Don Chapman Consultants, Inc.
Sherman Jensen, White Horse Associates, Inc.
Mark Kerr, Montana Natural Resource Damage Litigation Program
Joshua Lipton, Ph.D.,RCG/Hagler
Ann Maest, Ph.D., RCG/Hagler Bailly
Lyman McDonald, Ph.D., WEST, Inc.
Johnnie Moore, Ph.D., University of Montana
Glenn Phillips, Ph.D., Montana Department of Fish, Wildlife and Parks
William Platts, Ph.D., Don Chapman Consultants, Inc.
Dan Woodward, National Biological Survey

The following pages contain the signatures of these experts.

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Prepared by:

RCG/Hagler Bailly
P.O. Drawer O
Boulder, CO 80306-1906
(303) 449-5515

Testifying Experts:

Joshua Lipton, Ph.D.

Doug Beltman

Ann Maest, Ph.D.

JANUARY 1995

Harold Bergman
Dr. Harold Bergman
Department of Zoology and Physiology
University of Wyoming, Room 427
P.O. Box 3166
Laramie, WY 82071-3166

Dr. Tracy Hillman
Don Chapman Consultants, Inc.
3653 Rickenbacker, #200
Boise, ID 83705

Dr. Don Chapman
Don Chapman Consultants, Inc.
3653 Rickenbacker, #200
Boise, ID 83705

William S. Platts

Dr. William Platts
Don Chapman Consultants, Inc.
3653 Rickenbacker, #200
Boise, ID 83705

Tim Hardin, Ph. D

Tim Hardin, Ph.D.
Fishery Biologist
Hardin-Davis, Inc.
2910 NW Miller Lane
Albany, OR 97321

Sherman Jensen
Soil Scientist/Physical Ecologist
Box 123
Smithfield, UT 84335

Mark A Kerr

Mark A. Kerr
Natural Resource Damage Litigation Program
State of Montana
Department of Justice
Old Livestock Building
1310 East Lockey Avenue
PO Box 210425
Helena, Montana 59620-1425

Lyman McDonald

Lyman McDonald
Western EcoSystems Technolgy, Inc.
2003 Central Avenue
Cheyenne, WY 82001

Johnnie N. Moore, Ph.D
Department of Geology
University of Montana
Missoula, Montana 59812

Glenn Phillips, Ph.D
Montana Department of Fish, Wildlife and Parks
1420 East 6th Avenue
P.O. Box 200701
Helena, Montana 59620

Dan Woodward

Mr. Dan Woodward, Project Leader
National Biological Survey
Jackson Field Station
P.O. Box 1089
Jackson, WY 83001

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ACRONYMS

AET	Apparent Effects Threshold
ARCO	Atlantic Richfield Company
AWQC	Ambient Water Quality Criteria
CFS	Cubic Feet per Second
CRDL	Contract Required Detection Limit
CWA	Clean Water Act
DOI	United States Department of the Interior
EP	Ephemeroptera, Plecoptera
EPT	Ephemeroptera, Plecoptera, Tricoptera
GFAA	Graphite-Furnace Atomic Absorption Spectroscopy
ICP	Inductively-Coupled Plasma Spectroscopy
IDL	Instrument Detection Limit
IFIM	Instream Flow Incremental Methodology
KTL	Growth Condition Factor
LC	Lethal Concentration
LOEC	Lowest Observed Effects Concentration
LT	Lethal Time
MATC	Maximum Allowable Toxicant Concentration
MBMG	Montana Bureau of Mines and Geology
MDFWP	Montana Department of Fish, Wildlife, and Parks
MDHES	Montana Department of Health and Environmental Sciences
MDL	Method Detection Limit
MDOJ	Montana Department of Justice
MDSL	Montana Department of State Lands
MGD	Million Gallons per Day
MSD	Metro Storm Drain
MT	Metallothionein
NFCRC	National Fisheries Contamination Research Center
NOAA	National Oceanic and Atmospheric Administration
NOEC	No Observed Effects Concentration
NPL	National Priorities List
NRDA	Natural Resource Damage Assessment
NRDLP	Montana Natural Resource Damage Litigation Program
PCP	Pentacholorophenol
PHABSIM	Physical Habitat Simulation
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
QC	Quality Control
RIA	Radio Immunoassay
RI/FS	Remedial Investigation/Feasibility Study
RPD	Relative Percent Difference
SET	Severe Effects Threshold
SOP	Standard Operating Procedure

ACRONYMS

TR	Total Recoverable
TSS	Total Suspended Sediment
U.S. EPA	United States Environmental Protection Agency
U.S. FWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
WUA	Weighted Usable Area

1.0 INTRODUCTION AND SUMMARY

Aquatic resources of the upper Clark Fork River Basin have been injured as a result of historic and ongoing releases of hazardous substances. The upper Clark Fork River Basin Aquatic Resources Injury Assessment Report describes the results of injury determination and quantification for these aquatic resources. Resources addressed in this report include surface water, stream- and riverbed sediments, benthic macroinvertebrates, and fish. The geographic scope of the injury assessment (the assessment area) includes Silver Bow Creek (from below the Colorado Tailings in Butte to the Warm Springs Ponds) and the Clark Fork River (from its headwaters just downstream from the Warm Springs Ponds to the Milltown Reservoir)[1] (Figure 1-1).

The Aquatic Resources Injury Assessment Report describes injuries to surface water, benthic macroinvertebrates, and fish that have resulted from historic and ongoing releases of the hazardous substances arsenic, cadmium, copper, lead, and zinc from multiple sources associated with mining and mineral-processing operations in Butte and Anaconda. The following information on aquatic resources is presented in the various chapters of the Report:

Surface Water

- Surface water resources have been injured throughout the length of Silver Bow Creek and the Clark Fork River. These injuries have been caused by multiple exposures to hazardous substances.

- Surface water resources are exposed to hazardous substances released from multiple sources in the Butte and Anaconda areas. Surface water is exposed via upstream surface water, surface run-off, bed, bank, and floodplain sediments, and groundwater.

- Surface water serves as a pathway of hazardous substances to sediments and fish.

Sediments

- Stream- and riverbed sediments have been contaminated with hazardous substances throughout the length of Silver Bow Creek and the Clark Fork River from historic and ongoing releases from multiple sources in Butte and Anaconda.

[1] Hereafter, unless otherwise noted, the designations "Silver Bow Creek" and the "Clark Fork River" are used to refer to these geographic definitions.

- Sediments have been exposed to hazardous substances via upstream sediments, surface water, and surface run-off from contaminated floodplains.

- Contaminated sediments in Silver Bow Creek and the Clark Fork River act as a critical exposure pathway to injured surface water and aquatic biota, particularly benthic macroinvertebrates.

Benthic Macroinvertebrates

- Aquatic insects ("benthic macroinvertebrates") have been exposed to hazardous substances and injured throughout the length of Silver Bow Creek. These injuries have resulted from multiple exposures to hazardous substances.

- Benthic macroinvertebrates have been exposed to hazardous substances throughout the length of the Clark Fork River via surface water, sediments, and periphyton (attached algae on streambeds).

- Exposed and/or injured invertebrates act as a critical exposure pathway to injured fish.

Fish

- Fish have been injured throughout the length of Silver Bow Creek and the Clark Fork River. These injuries have been caused by multiple exposures to hazardous substances.

- Fish have been exposed to hazardous substances via surface water and contaminated prey (e.g., benthic macroinvertebrates).

- In Silver Bow Creek, trout populations have been eliminated entirely. In the Clark Fork River, trout populations have been substantially and statistically significantly reduced below baseline conditions. Rainbow trout largely have been eliminated from the Clark Fork River upstream of Rock Creek.

- Restoration of fish populations to baseline conditions requires restoration of surface water, sediments, and benthic macroinvertebrates; all serve as exposure pathways to injured fish.

Table 1-1 provides a summary of natural resource injuries and exposure pathways.

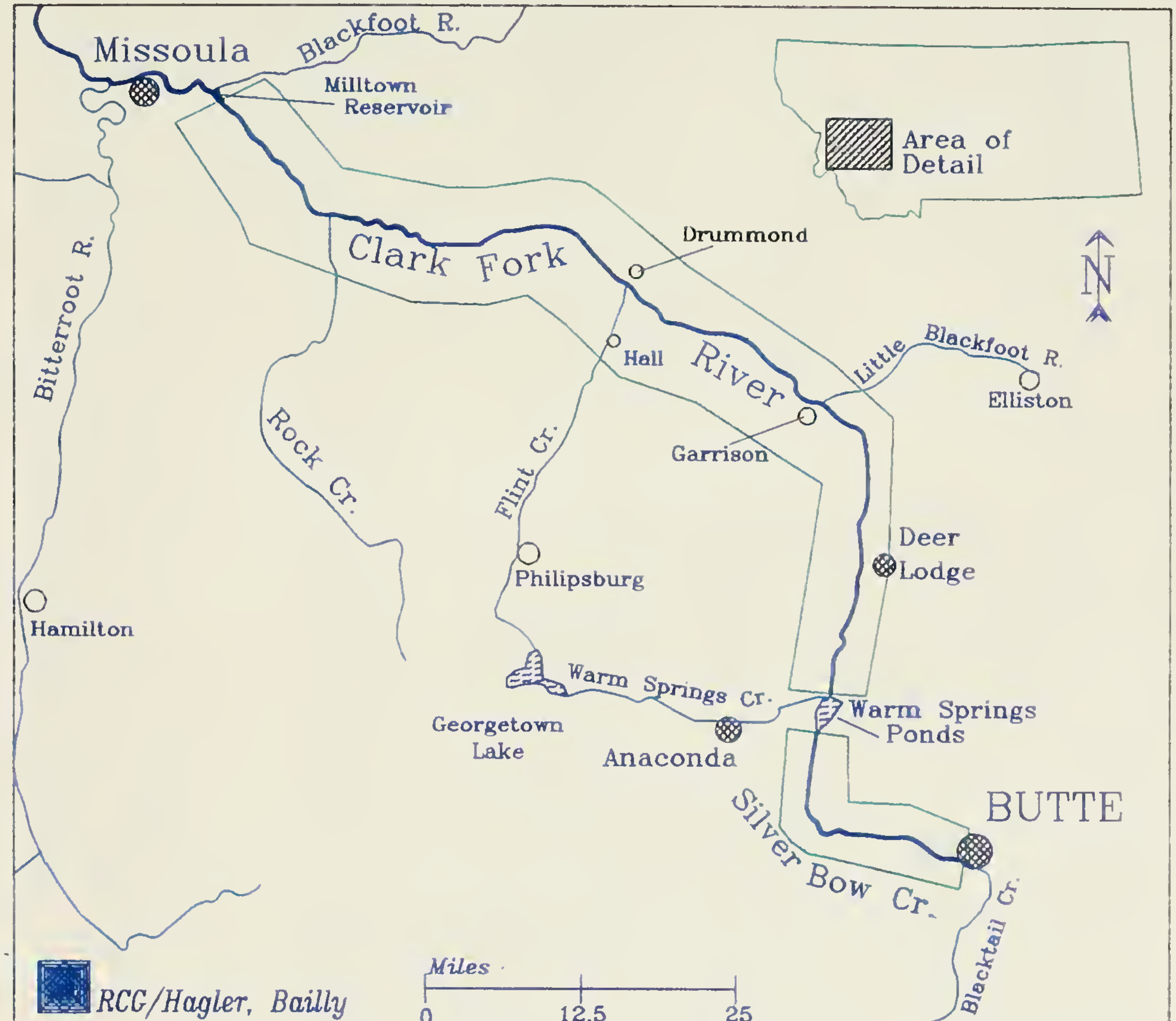

Figure 1-1. **Geographic Scope of Injury to Aquatic Resources: Silver Bow Creek and the Clark Fork River.**

Table 1-1
Injury Summary for Aquatic Resources

Natural Resource	Geographic Location	Injuries	Pathways to Injured Resource
Surface water	▸ Silver Bow Creek ▸ Clark Fork River	▸ Concentrations of hazardous substances exceed water quality criteria ▸ Concentrations of hazardous substances in surface water cause injury to fish	▸ Surface water, surface runoff ▸ Sediments (bed, bank, floodplain) ▸ Groundwater
Fish	▸ Silver Bow Creek ▸ Clark Fork River	▸ Death ▸ Behavioral avoidance ▸ Physical deformations ▸ Reduced growth	▸ Surface water ▸ Food chain (benthic macroinvertebrates)
Benthic macroinvertebrates	▸ Silver Bow Creek[1]	▸ Death ▸ Reduced biodiversity	▸ Sediments, surface water, periphyton

[1] The benthic macroinvertebrates of the Clark Fork River also serve as a pathway of hazardous substances to fish.

1.1 INJURY ASSESSMENT

The U.S. Department of the Interior (DOI) has promulgated regulations for the performance of natural resource damage assessments [43 CFR Part 11]. This assessment was performed in accordance with these regulations.

The term injury is defined as a

> measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a release of a hazardous substance, or exposure to a product of reactions resulting from the release of a hazardous substance. [43 CFR § 11.14 (v)].

The assessment of injury to aquatic resources of the Clark Fork River Basin included three steps. The first two steps constituted the injury determination phase, and the final step was the injury quantification phase:

- *Injury Definition.* In the injury definition phase, those injuries that were found to meet the definitions of injury in 43 CFR § 11.62 were evaluated.

- *Pathway Determination.* In the pathway determination phase, exposure pathways of hazardous substances to injured natural resources were identified [43 CFR § 11.63]. The DOI notes that pathway determination may be accomplished by the "demonstration of sufficient concentrations in the pathway for it to have carried the substance to the injured resources." [51 FR 27684]. In this assessment, "sufficient concentrations" of hazardous substances in pathway resources have been demonstrated in groundwater, surface water, bed, bank, and floodplain sediments, benthic macroinvertebrates, and periphyton.

- *Injury Quantification.* The effects of the releases of hazardous substances were quantified in terms of changes from "baseline conditions" [43 CFR § 11.70 (a)].

Baseline conditions are the conditions that "would have existed at the assessment area had the...release of the hazardous substance...not occurred" [43 CFR § 11.14 (e)] and are the conditions to which injured natural resources should be restored [43 CFR § 11.14 (ll)]. Baseline conditions should take into account both natural processes and human activities, and should include the normal range of physical, chemical, or biological conditions for the assessment area or injured resource [43 CFR § 11.72 (b)]. In addition, baseline data collection "shall be restricted to those data necessary for a reasonable cost assessment" [43 CFR § 11.72 (b)(4)]. Where historical baseline data are not available, "baseline data should be collected from control areas" [43 CFR § 11.72 (d)]. "Control area" is defined as "an area or resource unaffected by the...release of the hazardous substance under investigation. A control area or resource is selected for its comparability to the assessment area or resource and may be used for establishing the baseline condition and for comparison to injured resources" [43 CFR § 11.14 (i)]. Control area selection is based on criteria set forth at 43 CFR § 11.72 (d)(1-7):

- One or more control areas shall be selected based upon their similarity to the assessment area and lack of exposure to the . . . release.

- Where the . . . release occurs in a medium flowing in a single direction, such as a river or stream, at least one control area upstream or upcurrent of the assessment area shall be included, unless local conditions indicate such an area is inapplicable as a control area.

- The comparability of each control area to the assessment area shall be demonstrated, to the extent technically feasible, as that phrase is used in this part.

- Data shall be collected from the control area over a period sufficient to estimate normal variability in the characteristics being measured and should represent at least one full cycle normally expected in that resource.

- Methods used to collect data at the control area shall be comparable to those used at the assessment area, and shall be subject to the quality assurance provisions of the Assessment Plan.

- Data collected at the control area should be compared to values reported in the scientific or management literature for similar resources to demonstrate that the data represent a normal range of conditions.

- A control area may be used for determining the baseline for more than one kind of resource, if sampling and data collection for each resource do not interfere with sampling and data collection for the other resources.

Distinct control areas were identified for the assessment of injury to surface water, sediments, benthic macroinvertebrates, and fisheries. These control areas are described in greater detail in the individual injury chapters and accompanying appendices.

Source, Pathway, Exposure

The aquatic resources of Silver Bow Creek and the Clark Fork River that have been exposed to and/or injured by releases of hazardous substances include surface water and sediments, benthic macroinvertebrates, and fish. These natural resources also serve as pathways for contaminant movement within the aquatic ecosystem (Figure 1-2). For example, when hazardous substances are released from sources to surface water, they can accumulate in bed sediments. Hazardous substances in bed sediments, in turn, can expose surface water through chemical desorption reactions. Aquatic macroinvertebrates are exposed to hazardous substances from fine-grained bed sediments. Fish are exposed to hazardous substances through direct contact with contaminated surface water, and through consumption of these contaminated benthic macroinvertebrates.

The assessment of injury to aquatic resources included the following determination of source-pathway-exposure-injury relationships:

(1) Hazardous substances are found in significantly elevated concentrations (relative to baseline conditions) in multiple sources in the Butte and Anaconda areas, and are known to be released from those sources to pathway resources.

(2) Hazardous substances are found in elevated concentrations in pathway resources.

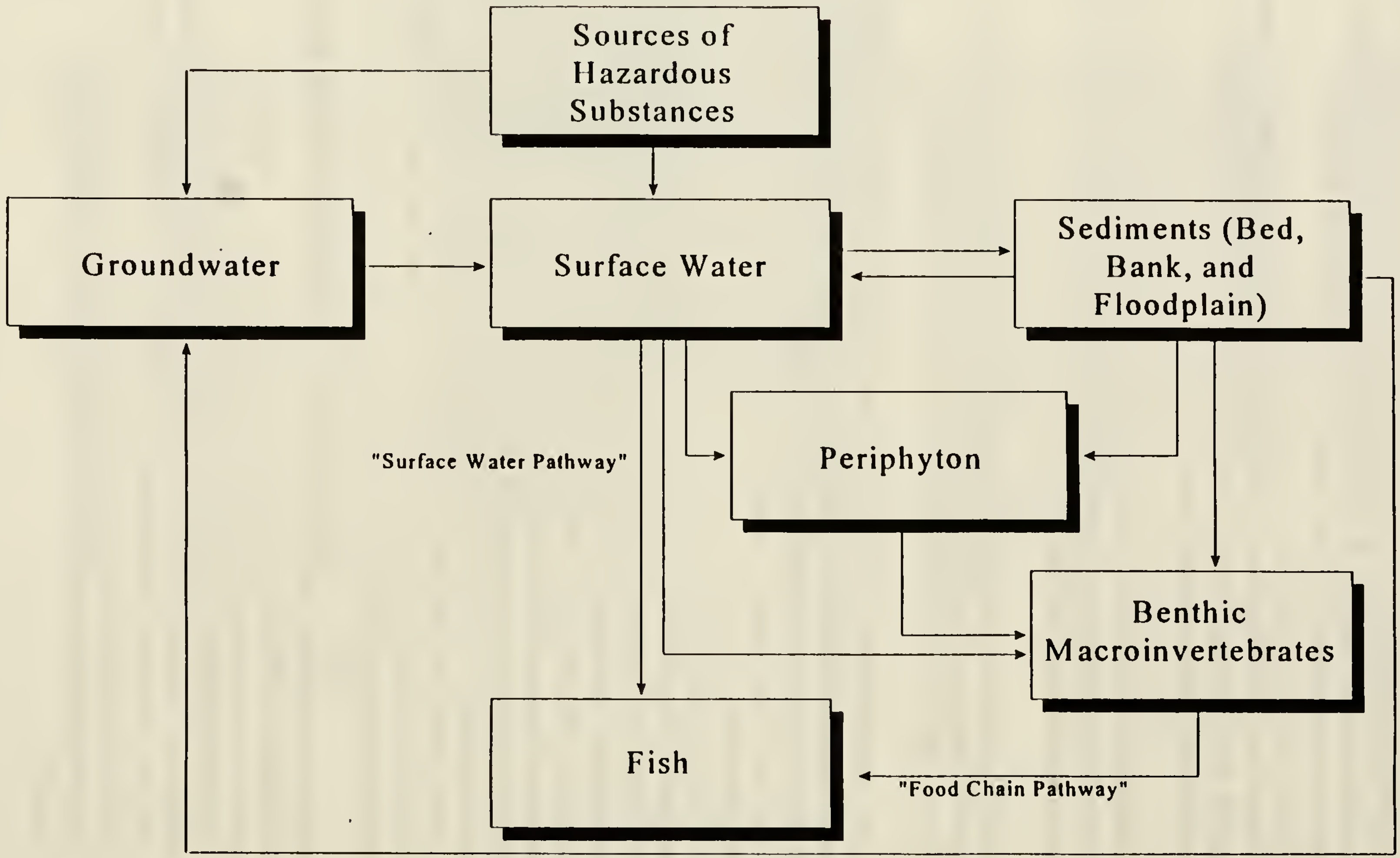

Figure 1-2. Relationships of Aquatic Resources Within the Clark Fork River.

(3) Natural resources are exposed to the pathway resources and, hence, to the hazardous substances in the pathways.

(4) The exposed natural resources have been injured. These injuries have been caused by exposure to the hazardous substances or their by-products that have been released from the Butte and Anaconda areas.

1.2 AQUATIC RESOURCE INJURY REPORT ORGANIZATION AND SUMMARY OF FINDINGS

As described previously, aquatic resources — including surface water, bed sediments, benthic macroinvertebrates, and fisheries — have been exposed and/or injured by hazardous substances in Silver Bow Creek and the Clark Fork River. These injuries to natural resources have resulted from historic and ongoing releases of the hazardous substances arsenic, cadmium, copper, lead and zinc, as well as compounds of these substances, from multiple sources in the Butte and Anaconda areas.

This aquatic resources injury report is organized as follows: **Chapter 2.0** describes sources of hazardous substances to aquatic resources. These sources of hazardous substances have been categorized extensively in Remedial Investigation/Feasibility (RI/FS) studies performed as part of Superfund activities at the four National Priorities List (NPL) sites in the Clark Fork River Basin.

Principal sources of hazardous substances released into the Silver Bow Creek/Clark Fork River aquatic environment include:

- Historic discharges from mines and mills located in the Butte and Anaconda areas

- Mine dumps, mill dumps, mining/smelting facilities, fill areas, and associated contaminated soils

- The Parrot Tailings impoundment and dispersed tailings in the Butte area

- The Butte Reduction Works Tailings impoundment

- The Colorado Tailings impoundment and dispersed tailings

- Fluvially deposited stream- and riverside tailings virtually devoid of vegetation covering at least 1,500 acres along Silver Bow Creek and the Clark Fork River, as well as at least an additional 5,000 acres of contaminated floodplain soils and sediments

- The Montana Pole and Treating Plant

- The Rocker Timber Framing and Treating Plant

- The settling ponds at Warm Springs ("Warm Springs Ponds")

- The Opportunity Ponds

- The Anaconda Smelter and proximate contaminated soils.

Chapter 3.0 presents information and data on concentrations of hazardous substances in bed sediments. These data demonstrate that sediments act as a critical exposure pathway from upstream sources in the Butte area to surface water and biota of Silver Bow Creek and the Clark Fork River.

Chapter 3.0, together with the Sediments Report prepared as part of this Assessment (Essig and Moore, 1992) demonstrates that:

- Concentrations of hazardous substances in bed sediments are significantly elevated above baseline conditions in Silver Bow Creek and the Clark Fork River.

- Bed sediment analysis identifies upstream sources in Butte and Anaconda to be the dominant and principal sources of hazardous substances to the Clark Fork River aquatic system.

- Other than Silver Bow Creek, tributaries to the Clark Fork River are *not* major sources of hazardous substances.

- Concentrations of hazardous substances in bed sediments to cause injury to aquatic benthic macroinvertebrates in Silver Bow Creek.

- Hazardous substances in bed sediments in the Clark Fork River are biologically available, and are bioaccumulated by benthic macroinvertebrates.

- Sediment concentrations of arsenic, cadmium, copper, lead, and zinc in Silver Bow Creek are well above sediment threshold concentrations (developed by the National Oceanic and Atmospheric Administration and the Ontario Ministry of the Environment) that are expected to adversely affect benthic communities.

- Sediments are a critical exposure pathway and therefore cause, and/or substantially contribute to, injuries to surface water, benthic macroinvertebrates, and, via food chain pathways, fish. Failure to restore bed sediments will therefore preclude restoration of these injured aquatic resources.

Chapter 4.0 describes injuries to surface water resources. This chapter shows that:

- Surface water resources of Silver Bow Creek and the Clark Fork River exceed ambient water quality criteria established under the Clean Water Act and hence have been injured.

- Surface water concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River are sufficient to cause injury to fishery resources.

- The injuries to surface water resources have been caused by exposure to a commingling of hazardous substances released from the Butte and Anaconda areas. The injuries to surface water represent a single harm caused by exposure to multiple hazardous substances.

Chapter 5.0 presents information and data specific to aquatic benthic macroinvertebrates. This chapter focuses on the uptake and accumulation of hazardous substances by macroinvertebrates which result in injury to fish that consume them. In addition, Chapter 5.0 demonstrates that invertebrates themselves have been injured in Silver Bow Creek. As described in this chapter, together with the Sediments Report (Essig and Moore, 1992):

- Hazardous substances in bed sediments of Silver Bow Creek and the Clark Fork River are bioavailable to benthic macroinvertebrates.

- Bioaccumulation of hazardous substances from contaminated Silver Bow Creek and Clark Fork River sediments by benthic macroinvertebrates has been documented in both field studies and controlled laboratory studies. Contaminated periphyton (algae) also serve as exposure pathways to benthic macroinvertebrates.

- Benthic macroinvertebrates in Silver Bow Creek have been injured by exposure to hazardous substances. Contaminated sediments from Silver Bow Creek were found to cause mortality to benthic macroinvertebrates. This mortality has caused the number of macroinvertebrate taxa in Silver Bow Creek to be reduced relative to baseline conditions.

- Injuries and exposure to benthic macroinvertebrates in Silver Bow Creek and the Clark Fork River have been caused by exposure to a commingling of hazardous substances released from the Butte and Anaconda areas. The

injuries to benthic macroinvertebrates represent a single harm caused by exposure to multiple hazardous substances.

Chapter 6.0, together with the Fisheries Toxicology Reports (Appendices B-F of this report) and the Fisheries Population Reports (Appendices G and H of this report), describe the determination and quantification of injury to trout populations in Silver Bow Creek and the Clark Fork River.

The results of **injury determination** for fishery resources include the following conclusions:

- Injuries to trout that have resulted from exposure to hazardous substances in surface water and in food-chains include death, behavioral avoidance, reduced growth, and physical deformations and health impairment.

- The multiple injuries to fishery resources represent a single harm — manifested in terms of reductions in trout populations — caused by exposure to the multiple hazardous substances released from the Butte and Anaconda areas.

- Death injuries have been confirmed in fish kills, *in situ* bioassays, and controlled laboratory studies.

- Fish kills have occurred frequently in the Clark Fork River.

- *In situ* bioassays have demonstrated significant mortality in the Clark Fork River and in Silver Bow Creek. The results of the fish kills and *in situ* bioassays present clear evidence that ambient concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River cause lethal injuries to trout.

- Laboratory studies demonstrated that exposure to acute pulses of elevated hazardous substances similar to those documented in the Clark Fork River causes significant trout mortality.

- Laboratory toxicity studies demonstrated that rainbow trout are more sensitive than brown trout to acute metals pulses in which pH and hardness decrease.

- Standard laboratory acute toxicity studies (LC_{50}, LT_{50} determinations) demonstrated that short-term exposure to copper, cadmium, lead, and zinc at concentrations documented in Silver Bow Creek and the Clark Fork River causes significant trout mortality. Small trout (fry) were more sensitive than larger trout (juveniles).

- Behavioral avoidance injuries have been confirmed by controlled laboratory studies. Both brown and rainbow trout avoid hazardous substances at concentrations regularly documented in Silver Bow Creek and the Clark Fork River. These studies also determined that rainbow trout are more sensitive than brown trout in avoiding hazardous substances.

- Behavioral avoidance likely limits the immigration of fish ("recruits") from tributaries into Silver Bow Creek and the Clark Fork River, and causes emigration to tributaries. Together, these responses contribute to adverse effects on resident populations.

- Laboratory studies documented that food-chain pathways injure trout. Fish fed diets of contaminated Clark Fork River invertebrates demonstrated increased mortality, decreased growth, and physiological health impairment.

- Reduced growth, a contributor to compromised survivability in the field, was documented in controlled laboratory studies. The weight of evidence suggests that growth has been reduced in free-ranging fish collected from the Clark Fork River.

- A consistent pattern of metal accumulation in tissues, degeneration of digestive cells (likely leading to reduced growth), cellular damage, and synthesis of metal-binding proteins required to detoxify/excrete metals (production of which entails a metabolic cost that has been shown to reduce growth and long-term survivability) was observed in both laboratory-exposed and free-ranging trout from the Clark Fork River.

The above conclusions all indicate the presence of multiple and pervasive injuries to resident fish of Silver Bow Creek and the Clark Fork River caused by exposure to hazardous substances.

The results of **injury quantification** for fishery resources demonstrate that the injuries that have been caused by exposures to hazardous substances represent a harm that collectively contributes to reductions in trout populations in Silver Bow Creek and the Clark Fork River. Exposure to hazardous substances has caused the total elimination of trout populations from Silver Bow Creek, substantial reductions in the number of trout present in the Clark Fork River, and reductions in the diversity of trout species in Silver Bow Creek and the Clark Fork River.

Specifically, the results of injury quantification studies supported the following conclusions:

- Trout have been entirely eliminated from Silver Bow Creek despite the availability of habitat.

- Overall, trout populations in the Clark Fork River are approximately one-sixth of baseline. These differences are not caused by differences in available habitat.

- Both brown trout and rainbow trout were substantially and statistically significantly more abundant at control sites.

- Rainbow trout largely are absent from the Clark Fork River upstream of its confluence with Rock Creek. This observation is consistent with the sensitivity of rainbow trout to hazardous substances.

- The observed reductions in trout populations in Silver Bow Creek and the Clark Fork River relative to baseline conditions are caused by exposure to hazardous substances; they are not caused by either habitat or flow differences.

Overall, the conclusion of this aquatic resource injury report is that multiple and, at times, continuous releases of the hazardous substances arsenic, cadmium, copper, lead, and zinc (and their compounds) from mining and mineral processing in Butte and Anaconda, have injured surface water, benthic macroinvertebrates, and fish. In addition, the releases have exposed sediments — a critical pathway resource — to elevated concentrations of hazardous substances throughout Silver Bow Creek and the Clark Fork River. Without restoration, the natural recovery time of these resources is estimated to be hundreds, if not thousands of years.

1.3 REFERENCE

Essig, D.A. and J.N. Moore. 1992. Clark Fork Damage Assessment: Bed Sediment Sampling and Chemical Analysis Report. Report to the State of Montana, Natural Resource Damage Program.

2.0 SOURCES OF HAZARDOUS SUBSTANCES TO AQUATIC RESOURCES OF SILVER BOW CREEK AND THE CLARK FORK RIVER

2.1 INTRODUCTION

This chapter describes sources of hazardous substances to Silver Bow Creek and the Clark Fork River. Data are provided on concentrations of hazardous substances measured in sources and source areas. This chapter is not intended to describe all sources and releases of hazardous substances; that information is contained in many reports prepared as part of the RI/FS. Rather, this chapter summarizes information regarding general source categories and areas.

Many sources in the Butte area were characterized during the Silver Bow Creek Remedial Investigation/Feasibility Study (SBC RI/FS). General source categories of hazardous substances to Silver Bow Creek and the Clark Fork River include historic discharges of mine and mill wastes; waste rock dumps; exposed and buried tailings impoundments; dispersed tailings; mine, mill, smelter and wood treating facility sites; and contaminated fill materials. The data and terminology used in various reports (MultiTech, 1987a, CH_2M Hill and Chen-Northern, 1990) to characterize these sources (particularly tailings impoundments, dispersed tailings, and associated contaminated materials) largely have been used in this chapter. Material types evaluated during the SBC RI/FS included tailings, mixed tailings and alluvium, fill material (e.g., alluvium, sand/gravel/slag, demolition and landfill debris, and waste rock), and underlying materials (peat, silts, sands, gravels) that have been exposed to hazardous substances via pathways. Elevated concentrations of arsenic, cadmium, copper, lead, and zinc were measured in many material types, including the exposed underlying organic materials. These underlying materials now serve as secondary sources of hazardous substances.

This chapter is organized as follows: Section 2.2 describes sources of hazardous substances to Silver Bow Creek, and Section 2.3 describes sources of hazardous substances to the Clark Fork River.

2.2 SOURCES OF HAZARDOUS SUBSTANCES TO SILVER BOW CREEK

The principal sources of hazardous substances to Silver Bow Creek (Figure 2-1) are:

1. Historic discharges from mines and mills.

2. Mine dumps, mill dumps, mining/smelting facilities sites, fill areas, and associated contaminated soils.

3. The Parrot Tailings impoundment and dispersed tailings in the Metro Storm Drain area.

4. The Butte Reduction Works Tailings impoundment and dispersed tailings in the Butte Reduction Works area.

5. The Colorado Tailings impoundment and dispersed tailings.

6. Approximately 1,300 acres of fluvially deposited streamside tailings along Silver Bow Creek.

7. The Montana Pole and Treating Plant.

8. The Rocker Timber Framing and Treating Plant.

These sources are described in Sections 2.2.1 through 2.2.8. Section 2.2.9 summarizes information concerning the solubility of hazardous substances in the various waste categories. Section 2.2.10 summarizes information on pathways from sources to Silver Bow Creek.

2.2.1 Historic Discharges from Mines and Mills

Wastes containing elevated concentrations of hazardous substances have been discharged directly to Silver Bow Creek and its tributaries for over 100 years since the onset of large-scale copper mining and mineral processing in Butte in the 1880s. Andrews (1987, as cited in Axtmann et al., 1991) estimated that until completion of the Warm Springs Ponds in the 1950s, more than 100,000,000 metric tons of mine and smelter tailings were released to Silver Bow Creek and Warm Springs Creek. MultiTech (1987b) calculated that as much as 6,600,000 cubic yards of tailings weighing 8,900,000 tons were produced by smelters in the Butte area from 1880 to 1930.

Early records and maps indicate that dams were built on the creek to contain tailings. An early map of the Butte and upper Silver Bow Creek area (Walcott, 1897) shows tailings dumps of the Colorado Smelter and Parrot Smelter encroaching on Silver Bow Creek. A map made in 1904 (F.C. Noble - probable author) shows waste deposits along the "Deer Lodge River" (Silver Bow Creek) near its confluence with Warm Springs Creek. A 1911 revision of this map by Noble shows wastes re-deposited downstream by high flows that occurred in 1908 and 1910 (Noble, 1911).

Discharge of contaminated minewater to Silver Bow Creek began in the 1880s (MultiTech, 1987b). In 1912, between 4,000 and 5,000 gallons per minute were pumped continuously from all mines in the Butte area (Meinzer, 1914). Most of this water was discharged to Silver Bow Creek (MultiTech, 1987b). Between 1901 and 1955, copper was precipitated

Figure 2-1. Source Areas, Silver Bow Creek.

from minewater before being discharged to Silver Bow Creek (MultiTech, 1987b). Between 1955 and 1972, minewater was used to leach low-grade ore from Anaconda Company's Berkeley Pit and, after copper precipitation, was discharged to Silver Bow Creek (MultiTech, 1987b; Spindler, 1976).

In 1964, the Weed Concentrator was constructed to concentrate and recover copper from the Anaconda Company's underground mines and the Berkeley Pit. Large amounts of wastewater generated during the concentration and recovery process were discharged to the Metro Storm Drain (MSD), which flows into Silver Bow Creek. By the early 1970s, an average of about 13 million gallons per day (MGD) and 6 MGD were discharged from the mill and leach circuits, respectively (Spindler, 1976). Improvements in water use and recycling in 1973 decreased the volume of discharged wastewater to approximately 12 MGD (6 MGD of process water overflow and 6 MGD of tailings pond overflow). Before closing in 1983, the Weed Concentrator discharged approximately 10 cfs (6.5 MGD) of wastewater containing hazardous substances into the Metro Storm Drain (MultiTech, 1987b, as cited in CDM, 1990).

Discharges of wastewater from the Weed Concentrator contained extremely elevated concentrations of hazardous substances. For example, Spindler (1976) calculated that copper and zinc concentrations in the discharges averaged 70 mg/l and 248 mg/l, respectively, during a 12 month period in 1971 and 1972. Spindler (1976) also summarized metals concentrations in the Weed Concentrator discharges from samples collected from the MSD one-quarter mile below the Butte Operations. These concentrations are summarized in Table 2-1 for portions of the years 1971, 1972, 1973, and 1975.

James (1980) reviewed existing water quality data for Silver Bow Creek, flow data from the Weed Concentrator discharge monitoring reports and contemporaneous studies (Peckham, 1979; Beuerman and Gleason, 1978). He calculated that the Weed Concentrator contributed approximately 7.2% of the copper and 2.4% of the zinc measured in Silver Bow Creek at Gregson.

In summary, mining and milling operations in the Butte area spanning nearly 100 years have been and continue to be sources of hazardous substances to Silver Bow Creek:

- Mine and mill wastes from numerous mining and milling sites were discharged, released, or deposited directly into Silver Bow Creek and its tributaries (MultiTech, 1987b). Early maps of Butte and Silver Bow Creek (e.g., Walcott, 1897; Noble, 1911) show tailings or other waste deposits in the Silver Bow Creek drainage adjacent to or downstream of mills and smelters along Silver Bow Creek.

- Discharge monitoring reports for the Weed Concentrator, which operated between 1964 and 1983, document elevated concentrations of hazardous substances in wastewaters discharged to Silver Bow Creek.

Table 2-1
Hazardous Substances in the Weed Concentrator Discharges
(concentrations in µg/l)[1]

Sampling Location and Date	Arsenic		Cadmium		Copper		Lead		Zinc	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Process water overflow to Metro Storm Drain[2]										
November 1972	NC	70	< 50	< 50	NC	2,450	< 100	100	NC	940
February 1973	NC	361	< 50	< 50	NC	19,000	NC	260	NC	2,800
March 1973	128	128	< 50	< 50	NC	3,000	110	150	NC	2,650
April 1973	1	1	< 50	< 50	NC	1,100	< 50	< 100	NC	260
May 1973	< 10	10	< 50	< 50	NC	600	< 100	150	NC	600
June 1973	< 10	10	< 50	< 50	450	950	< 100	< 100	170	1,500
July 1973	< 10	10	< 50	< 50	350	750	< 10	< 10	120	300
August 1973	NM	NM	NM	NM	NC	2,900	NM	NM	NC	550
December 1973	NM	NM	NM	NM	NC	120	NM	NM	NC	220
January 1974	NM	NM	4	4	120	430	< 100	< 100	50	70
February 1974	40	40	20	20	950	3,000	25	25	280	1,100
March 1974	90	220	< 10	< 10	380	950	< 50	< 50	< 120	580
April 1974	130	370	< 10	< 10	380	2,200	< 60	90	< 100	250
May 1974	116	195	8	10	350	1,600	57	70	90	530
July 1974	2	4	5	8	60	210	7	10	30	120
Tailings pond overflow to MSD[2]										
December 1973	2	3	< 50	< 50	NC	490	< 100	< 100	NC	980
January 1974	12	12	32	33	170	980	< 100	< 100	720	2900
February 1974	1	1	40	40	170	400	60	60	640	300
March 1974	43	164	15	30	210	1,000	< 50	60	1680	4500
April 1974	NM	NM	NM	NM	90	110	NM	NM	310	460
May 1974	28	95	11	12	45	60	35	75	120	280
July 1974	1	2	13	22	90	280	53	70	460	1700
MSD 1/4 mile below Butte Operations[3]										
Oct 1971 - Sept 1972	NC	NC	NC	NC	70,000	285,000	NC	NC	248,000	1,250,000
Oct 1972 - Sept 1973	NC	NC	NC	NC	1,440	22,400	NC	NC	2070	26,000
1975	NC	NC	NC	NC	100	240	NC	NC	170	350

1 NC = data not calculated. NM = no analyses made.
2 Anaconda Company, Butte Operations, Wastewater Monitoring Results Reports to Montana Department of Health and Environmental Sciences.
3 Spindler, 1976.

2.2.2 Mine Dumps, Mill Dumps, Mining/Smelting Facilities, Fill Areas, and Associated Contaminated Soils

A number of existing sources of hazardous substances have been identified in the Butte area, including mine dumps, tailings dumps, road fills, mine and mill sites, and associated contaminated soils and sediments. Hydrometrics (1983) identified over 100 inactive mines and associated waste dumps, containing some 10,000,000 cubic yards and 20,000,000 tons of material in a 12 square mile area within and north and west of Butte. Numerous mill sites, unreclaimed and reclaimed waste rock dumps, and drainages were characterized in the Butte Soils Screening Study (CDM, 1988). Table 2-2 provides hazardous substance concentrations at these source areas in Butte.

Many of these sites are located in surface and stormwater drainage basins which collect stormwater and snowmelt runoff from sources, and discharge to Silver Bow Creek via the storm drain systems. The drainage basins in Butte are Missoula Gulch, Buffalo Gulch, Idaho Street, Anaconda Road/Butte Brewery, West Side, Warren Avenue, Grove Gulch, and the Silver Bow Creek floodplain (CDM, 1991) (Figure 2-2). Runoff and sediment samples collected from these drainages contain elevated concentrations of arsenic, cadmium, copper, lead, and zinc (Tables 2-3 and 2-4).

Most sources in the Butte Priority Soils Operable Unit (BPSOU) are contained within the Missoula Gulch and Buffalo Gulch drainages, which transport runoff from Walkerville and the uptown Butte area to Silver Bow Creek (CDM, 1991). The upper portion of Missoula Gulch has been extensively disturbed by past mining activities and erosion of waste rock dumps in the drainage is visually evident (CDM, 1991). Surface runoff containing hazardous substances discharges from Missoula Gulch directly to Silver Bow Creek.

The Buffalo Gulch storm drain begins in the residential area northeast of Walkerville, and follows the historic drainage course. Between Walkerville and south Centerville, the drainage channel contains barren waste rock dumps, some of which are extensively eroded.

The Warren Avenue basin drains the east side of Butte, and discharges to the Metro Storm Drain. Sources of hazardous substances which are contained in the Warren Avenue drainage include mine waste dumps, inactive mines, and waste rock dumps (CDM, 1991). Water quality sampling (CH_2M Hill and Chen-Northern, 1990; Multitech, 1987, as cited in CDM, 1991) indicated that the water discharged from the Warren Avenue System contained elevated concentrations of metals and arsenic. The apparent sources of these hazardous substances are the mine waste dumps in the drainage (CDM, 1991).

The Anaconda Road-Butte Brewery storm sewer drains industrial and commercial areas adjacent to uptown Butte, and discharges to the Metro Storm Drain at Harrison Avenue. The drainage area contains numerous inactive mines and associated waste dumps; eroded mine wastes have been observed in the drainage (CDM, 1991).

Table 2-2
Hazardous Substance at Mill Sites and Waste Rock Dumps in the Butte Area
(concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	Arsenic	Cadmium	Copper	Lead	Zinc
Mill Sites[2] (Horizon "A")	Arithmetic Mean Maximum Minimum	457.2 3,560 23	33.1 294 1.7	1,248.9 8,600 47	3,647.3 58,300 55	6,166.2 53,300 127
Mill Sites (Horizon "B")	Arithmetic Mean Maximum Minimum	597.3 4,830 14	21.7 128 1.5	971.8 5,820 28.9	2,168.2 14,700 21	4,390.8 26,000 100
Mill Sites (Horizon "C")	Arithmetic Mean Maximum Minimum	448.4 6,090 15	17 106 3.2	1,105.1 11,200 35.4	1,611.1 9,440 14.1	3,989.9 30,300 154
Waste Rock Dumps[3] Unreclaimed (Horizon "A")	Arithmetic Mean Maximum Minimum	232.6 1,400 7.8	21.7 105 1.4	805.3 5,680 35.6	3,127.4 19,500 33.3	4,399.2 23,700 70.8
Waste Rock Dumps Unreclaimed (Horizon "B")	Arithmetic Mean Maximum Minimum	387.7 3,090 32	20.4 41 < 0.8	941.5 8,020 23.7	3,709.2 10,200 39.5	6,135.9 11,800 855
Waste Rock Dumps Unreclaimed (Horizon "C")	Arithmetic Mean Maximum Minimum	172.3 588 30.1	21.3 83 1.4	427.1 2,330 14.9	3,343 14,700 36	5,028.0 11,000 95.9
Waste Rock Dumps[4] Reclaimed (Horizon "A")	Arithmetic Mean Maximum Minimum	158.2 2,430 3.1	10.2 30 3.4	769.7 6,210 60	681.9 2,560 18.5	2,609.5 9,390 117
Waste Rock Dumps Reclaimed (Horizon "B")	Arithmetic Mean Maximum Minimum	295.4 2,020 18.3	9 19.8 2.8	536.7 2,380 35	586.5 2,480 45.7	1,564.8 4,340 139
Waste Rock Dumps Reclaimed (Horizon "C")	Arithmetic Mean Maximum Minimum	307.2 1,150 15.4	15.2 28.8 1.1	1,273.5 5,220 23	1,641.4 6,140 17	3,939.7 8,060 97.7
Drainages[5] (Horizon "A")	Arithmetic Mean Maximum Minimum	101.8 217.0 42	7.1 15.7 < 2	482.7 1,460 125	883.5 2,310.0 123	1,973.8 4,650 213

Table 2-2 (Continued)
Hazardous Substance at Mill Sites and Waste Rock Dumps in the Butte Area
(concentrations in mg/kg dry weight)[1]

Notes:

1 CDM, 1988. (Horizon "A": 0-1" or 0-6"; Horizon "B": 1-12" or 6-12"; Horizon "C": 12-24").

2 Mill sites include: Anaconda Sampling Works, Bluebird Mill, Burlington Mill, Butte Sampling Works, Colorado Smelter, Colorado Stamp Mill, Dexter Mill, Driggs and Oregon St., East of Substation, Grove Gulch Mill, Humane Society Mill, Kaw and George St., Lexington Mill, Margaret Ann Mill, Moulton Mill, Old Lexington, Parrot Smelter, Pittsmont Smelter, Timber Butte Mill, Timber Butte Tailings, Washoe Sampling Works, Weed Concentrator Area, other locales (tracks and drainages, old railroad cast of Timber Butte, eroded slope).

3 Unreclaimed waste rock dumps include: Alice Dump, Alliance, Amy, Anglo-Saxon, Anselmo (unreclaimed), Atlantic, Bell, Brewer Claim (north of), Charmer, Childe Harold, Colorado Leonard, Corra, Corra-2, Crusher Area Mines, East Gray Rock, Evaline Dump, Garibaldi, Glengarry Dump, Goldsmith (incline), Green Copper Disk, Heaney, Hibernia, Kelley, Laplata, Late Acquisition, Lexington Dump, Little Mina, Little Sarah Claim, Magna Carta, Minnie Irvine, Minnie Jane, Missoula NW Project, Moose, Mountain Con-1, Mountain Con (east of), Nettie, Nettie-2, Nonsuch Fraction, Oden, Old Glory (incline), Old Glory West, Ophir, Orphan Boy, Parrot (east and west sides), Paymaster, Penrose, Prospector, Rising Star, Robert Emmett, Rock Island, Sankey, Silver Queen, Steward, Syndicate Pit (waste north of), Tension, Travona, Venus Claim, Walkerville Landfill, Walkerville (northwest of), Williamsburg.

4 Reclaimed waste rock dumps include: Anselmo (reclaimed), Bonanza, Clear Grit, Colorado, Emma, Downey-1 (New Era), Gagnon, Henry and Quartz St., Missoula Mines, Mountain Con-2, National, New Era, Original, Ravin, Tom Gray, Tom Gray and West, West Gagnon, West Gray Rock.

5 Drainages include stormwater sewer and surface water drainages (See Table 2-3).

Overall:

- Over 100 separate waste dumps, rock dumps, mine and mill sites, and other areas of contamination have been identified in the Butte area. Waste mine dumps at inactive mines alone are estimated to contain approximately 10,000,000 cubic yards of material contaminated with hazardous substances (Hydrometrics, 1983).

- Elevated concentrations of hazardous substances have been measured in the sediments of various drainages which transport runoff from the Butte area (CDM, 1988).

Table 2-3
Hazardous Substances in Sediments of Butte Area Drainages
(concentrations in mg/kg dry weight)[1]

Drainage Location	Arsenic	Cadmium	Lead
Buffalo Gulch north of O'Neill St.	65	15.7	2,310
Buffalo Gulch at Ruby St.	106	12	2,100
Missoula Gulch	48.9	7.8	1,480
Laplata St.	138	6.6	1,130
Anaconda storm sewer outfall	217	8	715
Buffalo storm sewer outfall	113	4.6	708
Warren storm sewer outfall	76	9	421
Missoula Gulch storm sewer outfall	53	7	385
Idaho storm sewer outfall	141	0	216
Beef Straight Gulch	120	4.44	131
Westside storm sewer outfall	42	0	123

[1] Source: CDM, 1988 as cited in CDM, 1991.

- Elevated concentrations of hazardous substances have been measured in runoff from numerous surface drainages and underground storm drains which discharge to Silver Bow Creek (CH_2M Hill and Chen-Northern, 1990; PTI, 1989; MultiTech, 1987d, 1987e).

It is anticipated that these sources will be addressed by response actions under the Butte Priority Soils Operable Unit (BPSOU) Record of Decision (ROD), which should be issued in 1998 or 1999.

2.2.3 Parrot Tailings Impoundment and Dispersed Tailings in the Metro Storm Drain Area

Hazardous substance concentrations in waste and mixed waste materials in the upper and lower Metro Storm Drain (MSD) areas were characterized during the SBC RI Phase II (CH_2M Hill and Chen-Northern, 1990). Elevated concentrations of arsenic, cadmium, copper, lead, and zinc occur in all material types, including underlying materials of organic peat, silt, sand, and soil that have been exposed from the overlying hazardous substances (Tables 2-5 and 2-6).

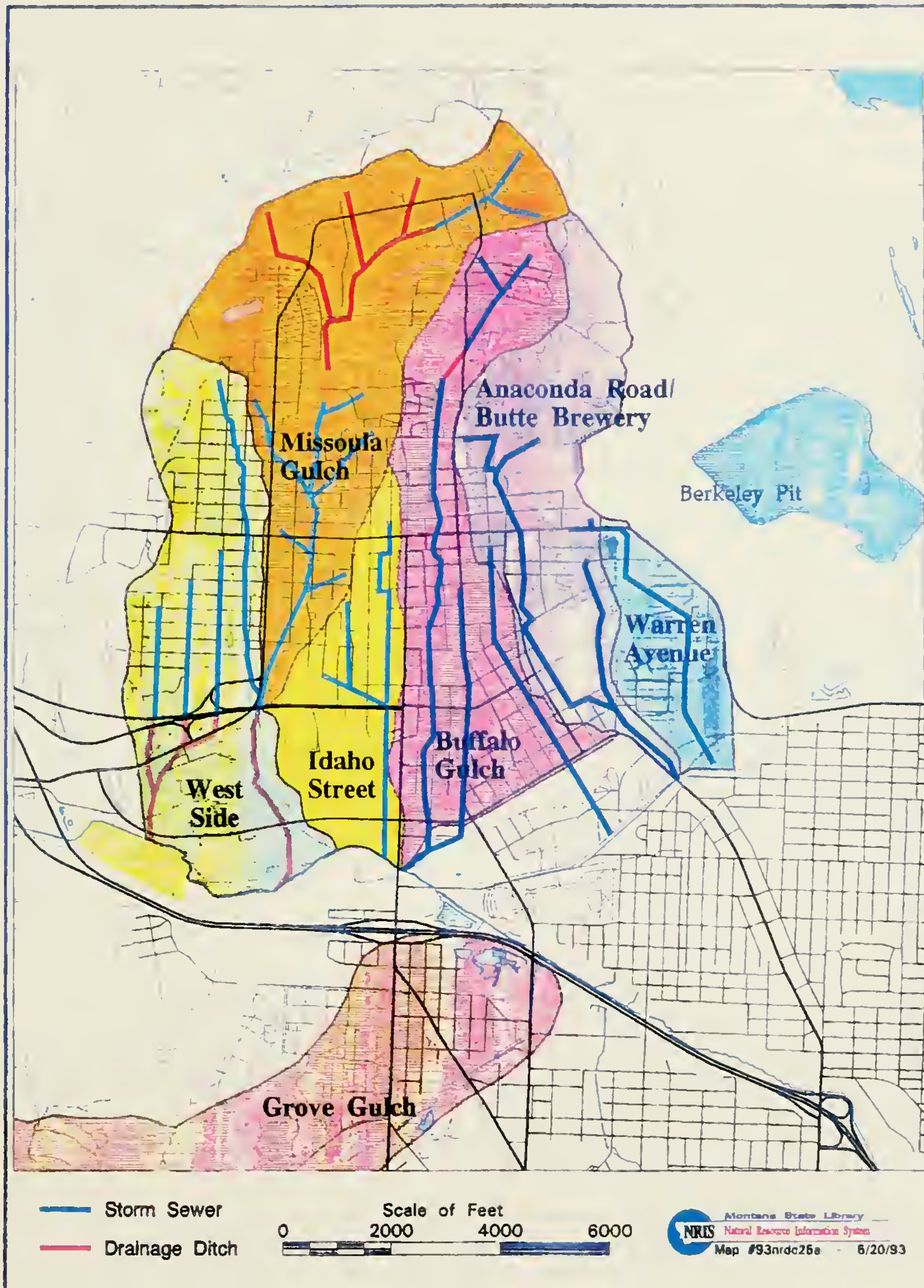

Figure 2-2. Butte Area Stormwater Basins.

Table 2-4
Hazardous Substances in Runoff to Silver Bow Creek
(concentrations in μg/l total)

Source (Receiving Stream)	Cd	Cu	Pb	Zn
Missoula Gulch (to Silver Bow Creek)				
Snowmelt runoff March 10, 1989[1]	26	611	334	2.190
Storm event May 29, 1985[3]	146	4,020	875	21,300
SBC RI monitoring December 3, 1984[3]	14	916	75	4,340
SBC RI monitoring April 8, 1985[3]	2.9	424	444	2,200
Kaw Avenue Storm Drain (to Metro Storm Drain)				
Snowmelt runoff March 10, 1989[1]	5	593	267	1.160
Storm event May 29, 1985[3]	25	1,490	448	3,790
Harrison Avenue Storm Drain (to Metro Storm drain)				
Snowmelt runoff March 10, 1989[1]	19	2,070	454	3,810
Weed Concentrator Complex (to Metro Storm Drain)				
Snowmelt runoff March 10, 1989[1]	90	17,400	454	16,800
Metro Storm Drain (to Silver Bow Creek)				
Snowmelt runoff March 10, 1989[1]	31	2,290	336	3,040
Base flow sampling September 1988[2]	21	311	5.1	7.370
Storm event May 29, 1985[3]	89	10,600	1.500	9.970
SBC RI monitoring December 3, 1984[3]	36	728	150	1.320
SBC RI monitoring April 8, 1985[3]	3.4	953	13	5,980
SBC RI monitoring July 22, 1985[3]	12	327	9.8	6.260

1 CH$_2$M Hill and Chen-Northern, 1990.
2 PTI, 1989.
3 MultiTech, 1987d, 1987e.

The Parrot Smelter operated from 1880 to 1910. The Parrot Tailings impoundment covers an area of approximately 30 acres in the upper MSD (MultiTech, 1987a). Historic photographs (circa 1955) show extensive tailings deposits in the upper MSD area (CH$_2$M Hill and Chen-Northern, 1990). Since 1955, large quantities of fill material have been deposited in the area and now cover nearly all previously exposed tailings and slag deposits, including the Parrot

Tailings (MultiTech, 1987a; CH$_2$M Hill and Chen-Northern, 1990). As much as 20 feet of fill material now covers tailings deposits, and mixtures of fluvial alluvium and tailings, as much as 12 feet thick (CH$_2$M Hill and Chen-Northern, 1990). Estimated volumes of waste and mixed waste materials containing hazardous substances in the upper Metro Storm Drain area include 190,000 cubic yards of tailings and mixed alluvium and tailings; 300,000 cubic yards of slag, slag-sand, and gravel; 525,000 cubic yards of waste rock; and 840,000 cubic yards of fill material; and 160,000 cubic yards of underlying organic soils. Approximately

Table 2-5
Hazardous Substances in Subsurface Materials of the Upper Metro Storm Drain (Area I Operable Unit)
(concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Covered tailings	Arithmetic mean	326	< 2	661	658	1,098
	Maximum	524	7	3,350	1,360	2,650
	Minimum	165	< 2	196	133	254
Mixed alluvium and tailings	Arithmetic mean	1,853	< 9	8,511	1,555	2,742
	Maximum	5,040	21	34,000	3,040	7,560
	Minimum	148	< 2	252	221	465
Transported fill: exposed underlying alluvium	Arithmetic mean	111	3	671	1,032	1,174
	Maximum	182	5	1,590	2,480	1,970
	Minimum	23	2	173	351	527
Transported fill: exposed sand/gravel, slag	Arithmetic mean	471	< 2	3,051	994	9,023
	Maximum	851	4	4,890	1,930	13,000
	Minimum	228	< 4	842	418	2,170
Transported fill: exposed demolition landfill	Arithmetic mean	78	12	863	2,680	22,400
	Maximum	78	12	863	2,680	22,400
	Minimum	78	12	863	2,680	22,400
Transported fill: waste rock	Arithmetic mean	59	0	279	148	46
	Maximum	113	0	409	198	90
	Minimum	20	0	112	85	19
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	593	< 8	5,017	149	1,581
	Maximum	2,870	38	21,900	499	4,370
	Minimum	12	< 1	953	35	719
Exposed underlying soils: sand, silt, gravel; upper 2 feet	Arithmetic mean	76	< 1	508	54	342
	Maximum	254	2	1,220	73	471
	Minimum	11	< 2	91	25	86
Exposed underlying soils: sand, silt, gravel; below 2 feet	Arithmetic mean	19	< 1	431	55	482
	Maximum	32	2	1,000	106	1,650
	Minimum	7	< 1	79	27	102

1 Source: CH_2M Hill and Chen-Northern, 1990.

Table 2-6
Hazardous Substances in Subsurface Materials
of the Lower Metro Storm Drain (Area I Operable Unit)
(concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Mixed alluvium and tailings	Arithmetic mean	406	< 9	2,559	509	4,211
	Maximum	818	28	8,560	1,020	10,500
	Minimum	207	< 1	303	241	958
Exposed underlying soils: (0-1")	Arithmetic mean	90	< 2	501	285	679
	Maximum	126	4	931	573	830
	Minimum	25	< 2	89	135	491
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	803	10	5,229	615	3,698
	Maximum	1,410	13	8,960	1,060	7,030
	Minimum	93	8	874	204	1,990
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	618	41	6,970	430	4,120
	Maximum	618	41	6,970	430	4,120
	Minimum	618	41	6,970	430	4,120

1 Source: CH_2M Hill and Chen-Northern, 1990.

650,000 cubic yards of these wastes (tailings, mixed alluvium and tailings, slag, and organic materials) are source areas of metals to underlying groundwater (CH_2M Hill and Chen-Northern, 1990).

Overall:

- The Parrot Tailings and associated dispersed tailings in the upper MSD contain elevated concentrations of arsenic, cadmium, copper, lead, and zinc, as characterized in the Silver Bow Creek Remedial Investigation (CH_2M Hill and Chen-Northern, 1990).

- Hazardous substances are present in concentrations and forms that are readily soluble in water (CH_2M Hill and Chen-Northern, 1990).

- Groundwater discharge to Silver Bow Creek in the Metro Storm Drain area contributes a substantial percentage of the metals load in the creek just below the Metro Storm Drain during low flow: cadmium (99%), copper (25%), lead (53%), and zinc (77%) (MultiTech, 1987d).

2.2.4 Butte Reduction Works Tailings and Dispersed Tailings in the Butte Reduction Works Area

The Butte Reduction Works was built about 1883 and operated nearly continuously until about 1911 (HRA, 1983, as cited in U.S. EPA, 1992). Between Montana Street and the Colorado Tailings, slag walls were built to retain the Works' tailings (CH_2M Hill and Chen-Northern, 1990; MultiTech, 1987a). Historical photographs show a series of tailings ponds, now buried, extending from the Colorado Tailings area to just below Montana Street (MultiTech, 1987b). Approximately 430,000 cubic yards of tailings and mixed tailings and alluvium, and 1,630,000 cubic yards of various types of waste, including manganese flue dust, railroad bed fill, and transported fill were deposited in the former Silver Bow Creek floodplain (CH_2M Hill and Chen-Northern, 1990). Source materials in the Butte Reduction Works area extend to a depth of 10-15 feet, and hazardous substances have been detected to a depth of 2 feet in underlying soils (CDM, 1991).

Elevated concentrations of hazardous substances occur in all material types, including underlying materials of organic peat, silt, sand, and soil that have been contaminated by overlying hazardous substances. Hazardous substance concentrations in subsurface samples of various material types are summarized in Table 2-7.

Emergency removal actions at Lower Area One, which includes the Butte Reduction Works and the Colorado Tailings (see Section 2.2.5), began at the Butte Reduction Works in 1993 and will continue until the late 1990s. Actions include the removal of a substantial quantity of tailings and associated contaminated wastes. Manganese tailings were removed in 1992. Tailings will be excavated over a period of several years. It is unlikely that all tailings and other waste materials will be removed. For example, tailings underlying the slag walls and other historic site structures will remain in place under remedy.
Overall:

- Approximately 1,630,000 cubic yards of wastes containing hazardous substances lie in the former Silver Bow Creek floodplain in Butte.

- Source materials contain extremely elevated concentrations of the hazardous substances arsenic, cadmium, copper, lead, and zinc.

- The inflow of contaminated groundwater from the Butte Reduction Works and the Colorado Tailings contributes substantially to exceedences of ambient water quality criteria for cadmium, copper, and zinc in Silver Bow Creek during baseflow and low flow conditions (CH_2M Hill and Chen-Northern, 1990; MultiTech, 1987, as cited in U.S. EPA, 1992).

Table 2-7
Hazardous Substances in Subsurface Samples from the Butte Reduction Works Area (Area I Operable Unit) (concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Covered tailings	Arithmetic mean	1,119	11	4,826	1,213	3,857
	Maximum	3,180	22	22,200	2,620	7,880
	Minimum	12	3	36	87	458
Mixed alluvium and tailings	Arithmetic mean	< 1,304	63	8,104	13,259	20.693
	Maximum	3,850	270	24,100	167,000	51,800
	Minimum	< 90	3	428	834	3,890
Transported fill: underlying alluvium	Arithmetic mean	89	1	242	324	706
	Maximum	89	1	242	324	706
	Minimum	89	1	242	324	706
Transported fill: sand/gravel, slag	Arithmetic mean	213	18	5,040	2,470	26.500
	Maximum	213	18	5,040	2,470	26,500
	Minimum	213	18	5,040	2,470	26,500
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	926	21	4,410	590	7,680
	Maximum	4,430	65	21,300	924	20,100
	Minimum	32	2	78	95	1.090
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	93	5	437	944	2.155
	Maximum	148	5	811	1,600	2.760
	Minimum	39	5	64	287	1.550
Exposed underlying soils: sand, gravel, silt; below 2 ft	Arithmetic mean	131	< 8	1,641	231	1,566
	Maximum	727	13	7,200	745	4,000
	Minimum	7	< 6	21	10	432

1 Source: CH_2M Hill and Chen-Northern, 1990.

2.2.5 Colorado Tailings Impoundment and Associated Dispersed Tailings

The Colorado Smelter was constructed in approximately 1879 and operated until about 1904. Tailings generated by this smelter were deposited in the Silver Bow Creek floodplain (U.S. EPA, 1992). The Colorado Tailings, which cover approximately 40 acres, consists of relatively continuous tailings material up to 4.5 feet deep, and additional fill material which covers underlying sediments and alluvium to a depth of 18 feet. Approximately 230,000 cubic yards of tailings and mixed tailings and alluvium, and 580,000 cubic yards of additional fill material are present in the Colorado Tailings (CH_2M Hill and Chen-Northern, 1990). Covered tailings, mixed alluvium and tailings, and underlying organic soils contain elevated concentrations of hazardous substances (Table 2-8).

Table 2-8
Hazardous Substances in Subsurface Materials from the Colorado Tailings Area (Area I Operable Unit) (concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Covered tailings	Arithmetic mean	1,089	11	5,989	1,152	4,052
	Maximum	2,500	23	16,700	3,280	7,680
	Minimum	553	2	123	268	808
Mixed alluvium and tailings	Arithmetic mean	1,175	22	5,544	2,501	10,685
	Maximum	2,900	55	14,400	6,640	22,000
	Minimum	451	2	586	258	1,030
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	841	< 39	9,389	799	10,505
	Maximum	2,910	113	25,600	2,990	31,800
	Minimum	35	< 4	355	40	257
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	134	< 2	1,102	253	1,463
	Maximum	320	5	2,030	652	3,830
	Minimum	32	< 5	136	50	253
Exposed underlying soils: sand, gravel, silt; below 2 ft	Arithmetic mean	713	< 1	534	21	188
	Maximum	1,420	1	978	32	290
	Minimum	6	< 1	90	11	86

1 Source: CH_2M Hill and Chen-Northern, 1990.

Tailings associated with Colorado Tailings have been dispersed along Silver Bow Creek for approximately one-half mile downstream of the impoundment. The creek channel has been extensively altered and channelized in the eastern half of this area. In the western half of this area, there is extensive evidence of fluvially deposited tailings adjacent to Silver Bow Creek and within associated meander channels (CH_2M Hill and Chen-Northern, 1990). Hazardous substance concentrations of various material types are summarized in Table 2-9.

A shallow groundwater system is present throughout the year beneath the Colorado Tailings. Groundwater movement through the tailings is generally from the southeast to the northwest, eventually discharging to Silver Bow Creek (Duaime et al., 1985). The base water table elevation is generally two to five feet below the tailings surface and appears to fluctuate in response to the surface water elevation of Silver Bow Creek (MultiTech, 1987a). Duaime et al. (1984, as cited in MultiTech, 1987a) reported that groundwater quality in the Colorado Tailings degrades significantly from southeast to northwest, the direction of groundwater flow within the tailings.

Table 2-9
Hazardous Substances in Subsurface Materials from the Area West of Colorado Tailings along Silver Bow Creek (concentrations in mg/kg dry weight)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Mixed alluvium and tailings	Arithmetic mean	269	< 3	1,626	3,246	3,942
	Maximum	529	7	4,270	6,700	8,120
	Minimum	12	< 5	17	9	70
Exposed underlying soils: organic silts, clays, peat	Arithmetic mean	104	8	575	1,340	3,690
	Maximum	104	8	575	1,340	3,690
	Minimum	104	8	575	1,340	3,690
Exposed underlying soils: sand, gravel, silt; upper 2 ft	Arithmetic mean	69	7	934	1,276	2,065
	Maximum	83	7	1,320	1,610	2,200
	Minimum	54	6	548	941	1,930
Exposed underlying soils: sand, gravel, silt; below 2 ft	Arithmetic mean	15	< 0	202	33	162
	Maximum	15	0	202	33	162
	Minimum	15	< 0	202	33	162

[1] Source: CH_2M Hill and Chen-Northern, 1990.

Excavation of the Colorado Tailings, which will occur as part of the emergency removal action at Lower Area One, began in 1994 and is expected to take three or four years. Although a substantial volume of tailings will be removed, and a significant reduction in metals loadings to Silver Bow Creek is expected to result from this action, it is unlikely that the entire waste deposited can or will be excavated. A groundwater collection and treatment system is envisioned to address remaining contamination and metals loadings to Silver Bow Creek.

Overall:

- The Colorado Tailings contain elevated concentrations of arsenic, cadmium, copper, lead, and zinc (CH_2M Hill and Chen-Northern, 1990).

- Hazardous substances are present in concentrations and forms that are readily soluble in water (CH_2M Hill and Chen-Northern, 1990).

- The Colorado Tailings contribute substantial amounts of hazardous substances to the local groundwater which discharges into Silver Bow Creek (MultiTech, 1987a, 1987d). Hazardous substances have been measured in Colorado

Tailings groundwater at concentrations as high as 5,000 μg/l (arsenic), 790 μg/l (cadmium), 98,000 μg/l (copper), 180 μg/l (lead), and 240,000 μg/l (zinc) (CH_2M Hill and Chen-Northern, 1990).

- Groundwater recharge from the Colorado Tailings contributes a significant proportion of the copper and zinc loadings to Silver Bow Creek (Duaime et al., 1990, as cited in U.S. EPA, 1992).

- Samples of surface runoff collected from the Colorado Tailings contain extremely elevated concentrations of hazardous substances. Hazardous substances in surface runoff have been measured at concentrations as high as 928 μg/l (cadmium), 233,000 μg/l (copper), 161 μg/l (lead), and 282,000 μg/l (zinc). These concentrations are orders of magnitude greater than federal ambient water quality criteria (see Chapter 4.0).

2.2.6 Fluvially Deposited Streamside Tailings

Contaminated sediments transported by Silver Bow Creek have been deposited on its floodplain as a result of increased sediment loading and channel aggradation[1] during high water events, and as a result of downstream erosion and re-deposition of contaminated material. The addition of large quantities of sediment and mine wastes to Silver Bow Creek resulted in aggradation of the river channel. The channel clogging resulted in the development of a braided stream pattern which progressed downstream. Former stream channels are evident in aerial photographs (GCM Services, Inc., 1983, as cited in MultiTech, 1987b).

Currently, virtually the entire Silver Bow Creek floodplain is contaminated with fluvially deposited mixtures of mill tailings, mine waste, and sediment (CH_2M Hill and Chen-Northern, 1990). Various estimates of floodplain tailings have been made by several investigators. Peckham (1979) estimated that approximately 1,700,000 cubic meters (2,300,000 cubic yards) of mine tailings containing 9,000,000 kilograms (20,000,000 pounds) of copper and 18,000,000 kilograms (39,000,000 pounds) of zinc were deposited along Silver Bow Creek. Canonie (1992) estimated that 3,700,000 to 7,800,000 cubic yards of tailings and tailings-impacted material are contained within the Streamside Tailings Operable Unit (below the Colorado Tailings to Warm Springs). Between the Colorado Tailings and Durant Canyon, approximately 1,700,000 to 4,100,000 cubic yards of tailings and mixed tailings and alluvium were deposited. The most prominent feature of this reach is Ramsay Flats, a 160-acre fluvial deposit of barren tailings and mixed tailings and alluvium. Between the upstream end of

[1] Modification of the channel bed in the direction of uniformity of grade by deposition; in this case, "filling in" of the channel.

Durant Canyon and Finlen, an estimated 733,000 to 965,000 cubic yards of tailings and mixed tailings and alluvium were deposited. Between Finlen and the Warm Springs Ponds, an estimated 1,300,000 to 2,800,000 cubic yards of tailings and mixed tailings and alluvium were deposited (Canonie, 1992). Hydrometrics (1983) estimated that tailings cover 1,270 acres of floodplain (see Figure 2-3). Titan (1994) estimated that 1304 acres of floodplain have been affected by fluvially deposited tailings.

Chemical analyses of floodplain materials indicate that tailings contain elevated concentrations of hazardous substances and low pH. The presence of hazardous substances in floodplain tailings and riparian soils has been confirmed by many studies (e.g., MSU et al., 1989; MultiTech, 1987a; CH_2M Hill and Chen-Northern, 1990; Peckham, 1979). All data indicate that tailings deposits, other mine wastes, and soils impacted by tailings have extremely elevated concentrations of arsenic, cadmium, copper, lead, and zinc (Table 2-10).

Streamside tailings are subject to erosion and entrainment during high flows. Increased loadings of arsenic, copper, lead, and zinc from channel or bank scouring during higher flows is significant in reaches from the Colorado Tailings to Silver Bow, and from Ramsay Flats to Fairmont Hot Springs (MultiTech, 1987d). Re-entrainment and transport of streamside tailings constitutes a continuing release of hazardous substances.

As a result of hazardous substance releases to and transport within Silver Bow Creek, suspended, bank, and bed sediments throughout the creek are contaminated with hazardous substances relative to baseline (see Chapter 3.0). Recent investigations have also documented the discharge of groundwater contaminated by streamside tailings to Silver Bow Creek in the Miles Crossing area above Durant Canyon (Moore, J.N., University of Montana, *pers. comm.*, 1994).

Overall:

- Elevated concentrations of hazardous substances have been measured in tailings and floodplain sediments by numerous investigators.

- Elevated concentrations of hazardous substances have been measured in surface runoff from Ramsay Flats, the largest barren tailings deposit along Silver Bow Creek (CH_2M Hill, 1987).

- Significant increases in arsenic, copper, lead, and zinc loadings in Silver Bow Creek from channel or bank material during high flows were documented in two reaches (Colorado Tailings to the town of Silver Bow, Ramsay Flats to Gregson bridge) (MultiTech, 1987d). Loadings in these two reaches averaged approximately two pounds per day of arsenic, four pounds per day of lead, 23 pounds per day of copper, and 26 pounds per day of zinc.

Table 2-10
Hazardous Substances in Tailings and Floodplain Sediments of Silver Bow Creek
(average concentrations in ppm)

Location on Silver Bow Creek	As	Cd	Cu	Pb	Zn
Montana Street to the Upper Metro Storm Drain[1]					
▸ Exposed tailings	601	9	1,523	644	2,854
▸ Floodplain sediments/mixed alluvium					
and tailings	306	10	1,936	773	4,217
▸ Waste rock - railway roadbed fill	298	3	1,389	421	857
▸ Waste rock - transported fill and	113	< 4	552	265	1,571
alluvium	97	5	570	565	1,101
▸ Soil					
	485	6.5	220	1,280	3,970
Below Colorado tailings to Miles Crossing[2]					
	399	13.4	2,350	989	3,070
Ramsay Flats					
	371	6.2	2,030	1,040	2,920
Miles Crossing to Warm Springs Ponds[2]					
	678	17.3	2,520	1,480	3,790
Butte to the Mill-Willow Bypass[4]					
	340	6.3	1,392	463	1,887
Colorado Tailings to Warm Springs Ponds[5]					

[1] CH_2M Hill and Chen-Northern, 1990.
[2] Canonie, 1992.
[3] MultiTech, 1987a.
[4] MSU et al., 1989.
[5] Lipton et al., 1995.

2.2.7 Montana Pole and Treating Plant

The Montana Pole and Treating Plant began operation in 1946. Modifications in 1949 and 1956 included the addition of two retorts for pressure-treating wood with a diesel/ pentachlorophenol mixture (Boulton process). Process wastewater was reportedly discharged to a ditch which flowed to Silver Bow Creek. An explosion and fire on May 5, 1969 resulted in spillage of petroleum/PCP product. On May 17, 1984 all operations at the site were discontinued (Keystone, 1991).

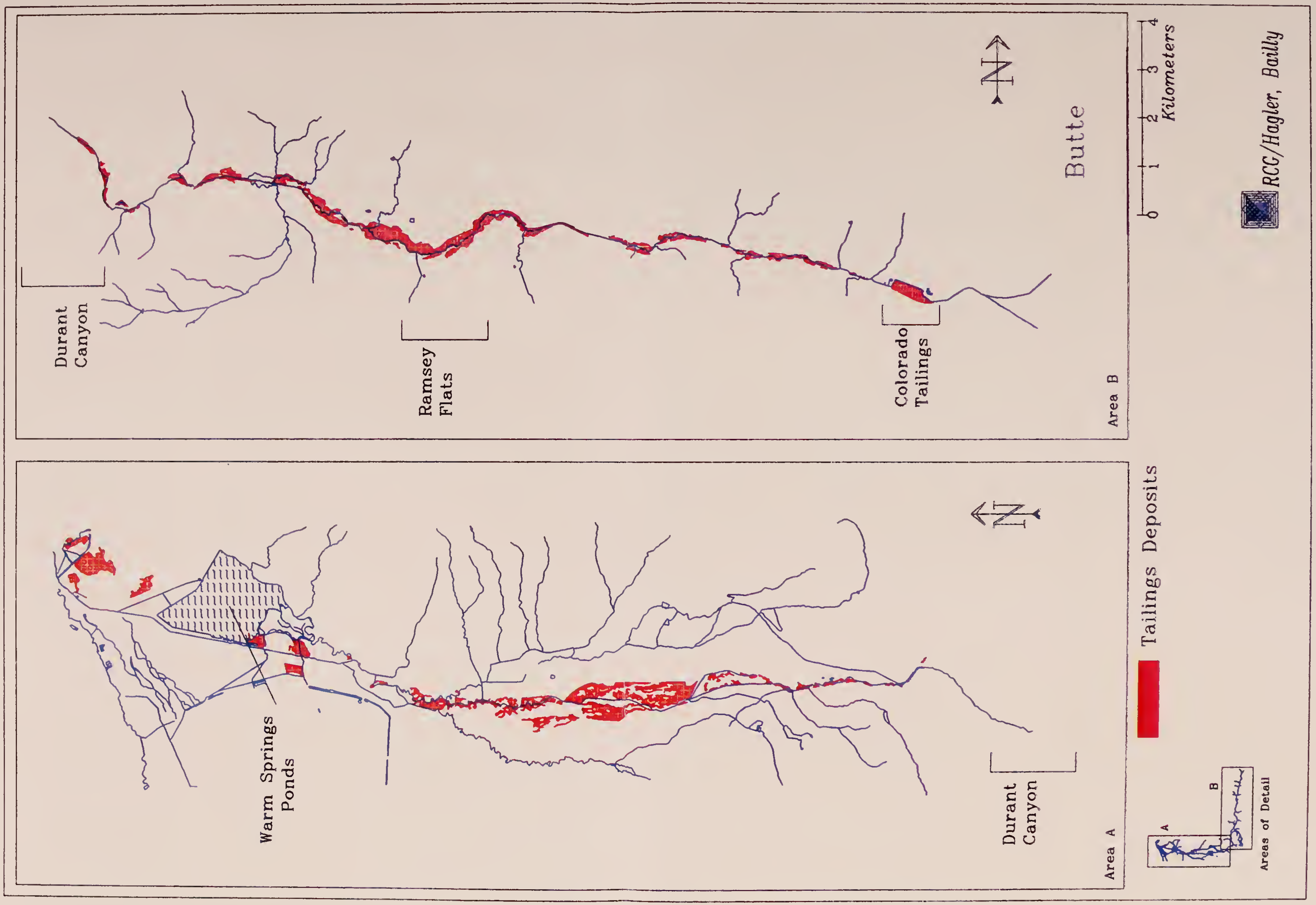

Figure 2-3. Floodplain Tailings Deposits, Silver Bow Creek.

Sources of hazardous substances at the Montana Pole Site include spillage (especially from the mixing tanks), drippings from treated wood, leaking pipelines used to transfer products, the drainage ditch that received process wastewater from the plant, the catchment area below the retorts, water discharged from clarifying tanks, the mixing vat, and areas where condensate pooled during discharge (Keystone, 1992e, as cited in ARCO, 1993).

Elevated concentrations of hazardous organic substances have been found in the surface and subsurface soils in the former process area and along the drainage ditches (ARCO, 1993). The highest concentrations of pentachlorophenol (PCP) and other organic compounds in the subsurface were generally found in samples collected at or near the water table.[2] In addition, wells located near Silver Bow Creek contain arsenic, cadmium, copper, lead, and zinc, likely the result of mining-related wastes (ARCO, 1993).

Table 2-11 summarizes concentrations of hazardous substances in the groundwater underlying and surface water (Silver Bow Creek) adjacent to the Montana Pole and Treating Plant. As a result of ongoing or planned response actions at this site, contaminated soils will be excavated and groundwater will be treated and discharged to Silver Bow Creek.

2.2.8 Rocker Timber Framing and Treating Plant

The Rocker Operable Unit of the Silver Bow Creek/Butte Area NPL site is located approximately seven miles west of Butte and is bordered to the north by Silver Bow Creek (Keystone, 1992). It is the site of the former Rocker Timber Framing and Treating Plant, which operated from approximately 1900 until approximately 1957. The plant treated mine timbers with a preservative containing arsenic.

The surface and subsurface soils still contain elevated levels of arsenic. One sample at the 9- to 11-foot sampling interval had an arsenic concentration of 42,900 mg/kg. Elevated levels of cadmium, copper, lead, mercury, and zinc are also present. There are also load increases of total arsenic, copper, and lead between surface water stations located upstream and downstream of the Rocker Operable Unit. Streambed sediments at the Rocker Operable Unit also contain arsenic, cadmium, copper, lead, and zinc (Keystone, 1992).

[2] Organic hazardous substances are released to Silver Bow Creek by the site groundwater, as evidenced by the oily seeps observed along the streambank (ARCO, 1993).

Table 2-11
Hazardous Substances in Groundwater and Surface Water at the Montana Pole and Treating Plant (concentrations in ppb)[1]

		Organic Compounds[2]				Inorganic Compounds[3]				
Media	Statistical Parameter	PCP	PAH	BTEX	2,3,7,8-TCDD or equivalent	As	Cd	Cu	Pb	Zn
Groundwater	Arithmetic mean	3,830	51,770	40	NC	40	20	1,470	NM	5,340
	Maximum	880,000	3,668,691	1,300	0.0537	1,570	232	34,600	NM	75,200
	Minimum	0.5	0.02	0.39	0.0010	0.2	2.5	12.5	NM	10
Surface water	Arithmetic mean	75	9	NM	NM	18	2.5	156	11	614
	Maximum	591	49.53	NM	NM	25.2	2.5	220	30.3	1,120
	Minimum	0.5	0.3	NM	NM	12.9	2.5	93.6	2.5	262

1 Source: Keystone, 1992e, as cited in ARCO, 1993.
2 PCP = Pentachlorophenol; PAH = Polynuclear aromatic hydrocarbons (total); BTEX = Benzene, toluene, ethylbenzene, xylene (total); TCDD = Dioxin; NC = not calculable.
3 As = Arsenic; Cd = Cadmium; Cu = Copper; Pb = Lead; Zn = Zinc; NM = not measured.

2.2.9 Solubility of Hazardous Substances in Waste Deposits

The previous sections identified and described general source categories of hazardous substances to Silver Bow Creek. During the SBC RI/FS, 20 surface material samples were analyzed for water soluble substances to evaluate the potential impact of surface runoff on receiving waters. The data indicate that sources contain hazardous substances which readily solubilize in water (Tables 2-12 and 2-13). Runoff collected from exposed surface tailings deposits also contains elevated concentrations of hazardous substances (Table 2-14). The high solubility of these materials makes them readily released to surface water during precipitation events.

Table 2-12
Water-soluble Hazardous Substances in Surface Materials (0-1")
(Area I Operable Unit)
(concentrations in µg/l)[1]

Area	Material Unit	As	Cd	Cu	Pb	Zn
Upper Metro Storm Drain	Mixed tailings and alluvium	46	100	41,000	< 0.4	21,000
	Railway roadbed fill	3,900	89	27,000	1.8	25,000
	Transported fill (sand, gravel with slag, waste rock)	15	370	730	< 0.4	86,000
Lower Metro Storm Drain	Mixed tailings and alluvium	7.1	220	3,300	< 0.4	92,000
	Mixed tailings and alluvium	25	280	750	< 0.4	110,000
	Mixed tailings and alluvium	110	< 0.1	40	< 0.4	40
	Mixed tailings and alluvium	3.8	22	1,300	1.3	27,000
	Mixed tailings and alluvium	9.2	100	57	< 0.4	26,000
	Mixed tailings and alluvium	130	0.11	91	0.8	21
	Mixed tailings and alluvium	3.8	10	98	< 0.4	1,400
Butte Reduction Works	Exposed tailings	3.7	470	370,000	< 0.4	150,000
	Covered tailings	8,900	1,800	900,000	< 0.4	660,000
	Manganese stockpile	9.3	< 0.1	< 6	< 0.4	86
	Railway roadbed fill	12	26	8,100	1.3	21,000
	Railway roadbed fill	20	2,000	42,000	6.7	670,000
Colorado Tailings	Exposed tailings	34	< 0.1	7.0	< 0.4	20
	Transported fill	9.8	360	150	< 0.4	39,000
West of Colorado Tailings	Mixed alluvium and tailings	12	350	23,000	< 0.4	70,000

[1] Source: CH_2M Hill and Chen-Northern, 1990.

Table 2-13
Water-soluble Hazardous Substances in Subsurface Materials
(Area I Operable Unit)
(concentrations in µg/l)[1]

Material Unit	Depth (ft)	As	Cd	Cu	Pb	Zn
Upper Metro Storm Drain						
Mixed tailings and alluvium	1.3 - 2.5	260	290	820,000	< 0.4	33.000
Transported fill: sand/gravel, slag	2.0 - 5.5	< 3	73	270	4.8	20,000
Covered tailings	22 - 25.3	140	1.8	1,700	8	640
Lower Metro Storm Drain						
Mixed tailings and alluvium	0 - 1.2	4.9	66	660	< 0.4	11,000
Mixed tailings and alluvium	1.7 - 2.4	5.3	0.72	140	2.2	310
Butte Reduction Works						
Covered tailings	2.8 - 3.7	16	240	520,000	2.0	100,000
Covered tailings	2.0 - 3.5	24	40	300	10	14,000
Mixed tailings and alluvium	6.0 - 9.5	18	180	6.0	800	23,000
Mixed tailings and alluvium	0.8 - 2.8	23	4,100	330,000	15	740,000
Colorado Tailings						
Covered tailings	2.4 - 2.8	86	120	170,000	5.4	39,000
Covered tailings	1.0 - 3.0	23	31	180,000	9.8	7,000
Exposed underlying soil: organic silts, clays, peat	1.5 - 2.5	9.5	330	100	0.9	22.000

[1] Source: CH_2M Hill and Chen-Northern, 1990.

2.2.10 Pathways of Hazardous Substances from Sources to Silver Bow Creek

Pathways by which hazardous substances migrate to Silver Bow Creek are groundwater, surface water, and sediments. Migration of hazardous substances by the discharge of contaminated groundwater has been documented by numerous investigators, as discussed in Lipton et. al. (1995), Chapter 4.0. Surface water acts as a pathway to surface water by way of runoff over waste materials, and by way of riverine transport (surface water in upstream reaches moving to downstream reaches). The surface water pathway is discussed in more detail in Lipton et. al. (1995), Chapter 4.0. Sediments and associated wastes have migrated from the Butte and Anaconda areas to reaches of Silver Bow Creek. This is further discussed in Lipton et. al. (1995), Chapter 3.0.

Table 2-14 Hazardous Substances in Surface Runoff from Tailings Deposits to Silver Bow Creek (concentrations in µg/l total recoverable)				
Source (Receiving Stream)	**Cd**	**Cu**	**Pb**	**Zn**
Colorado Tailings (to Silver Bow Creek)				
Snowmelt runoff March 10, 1989[1]	74	21,100*	87	27,200
Storm event runoff July 8, 1986[2]	928	233,000	161	282,000
Ramsay Flats (to Silver Bow Creek)				
Storm event runoff July 16, 1986[2]	1250	202,000	3100	264,000

* Indicates acid soluble concentration.

1 CH_2M Hill and Chen-Northern, 1990.
2 CH_2M Hill, 1987.

2.3 SOURCES OF HAZARDOUS SUBSTANCES TO THE CLARK FORK RIVER

Numerous sources contribute to hazardous substances to the Clark Fork River. Silver Bow Creek transports hazardous substances from sources in the Butte area and from streamside tailings to the Warm Springs Ponds, which discharges to the Clark Fork River. Therefore, the numerous historic and existing sources of hazardous substances throughout the Silver Bow Creek drainage from Butte to the Warm Springs Ponds, including the many mining and milling facilities that discharged wastes to Silver Bow Creek that now comprise the floodplain tailings that exist along virtually the entire length of Silver Bow Creek, are ultimately sources to the Clark Fork River. Other sources of hazardous substances to the Clark Fork River include sources in the Anaconda area related to the past operation of the Anaconda Smelter (i.e., the Opportunity Ponds, a repository for the Anaconda Smelter tailings; lands contaminated by emissions from the Anaconda Smelter; and numerous wastes along Warm Springs Creek); and riverside tailings along the Clark Fork River. These sources are described in the following subsections.

2.3.1 Warm Springs Ponds

The Warm Springs Ponds were designed to collect mining-related wastes and associated contaminated sediments transported by Silver Bow Creek from sources in the Butte area. Ponds 1 and 2 were constructed prior to 1920; Pond 3 was constructed between 1954 and 1959 (Hydrometrics, 1983a, as cited in MultiTech, 1987c). The Warm Springs Ponds contain an estimated 18,960,000 cubic yards of sediment containing elevated concentrations of hazardous substances (Table 2-15) (MDHES and CH_2M Hill, 1989).

Table 2-15
Hazardous Substances in Pond Bottom Sediments
(concentrations in mg/kg dry weight)[1]

Location	Statistical Parameter	As	Cd	Cu	Pb	Zn
Pond 1	Arithmetic mean	408	10	2,886	670	2,212
	Maximum	17	66	9,390	1,920	7,900
	Minimum	7	1	19	8	70
Pond 2	Arithmetic mean	590	36	4,661	726	4,859
	Maximum	1,910	291	15,700	1,670	28,200
	Minimum	10	1	62	10	49
Pond 3	Arithmetic mean	301	195	7,015	252	17,319
	Maximum	1,630	659	16,400	680	45,800
	Minimum	18	1	107	9	114
Wildlife Ponds	Arithmetic mean	42	8	439	54	855
	Maximum	94	20	1,160	126	2,380
	Minimum	12	1	50	54	77
Baseline[2]	Minimum	7	0.22	20	15.4	56.5

1 Source: MDHES and CH_2M Hill, 1989.
2 See Chapter 3.0.

Hazardous substances in the Warm Springs Ponds are released to the Clark Fork River through the Pond 2 discharge. Recent remedial activities are intended to upgrade the treatment capacity and efficiency of the Ponds. Fine-tuning of the enhanced treatment system will occur over the next several years. Nonetheless, concentrations of hazardous substances in the discharge exceeded ambient water quality criteria as recently as 1993 (Table 2-16). In the past several years, zinc has also exceeded ambient water quality criteria. Upon completion of remedial activities, the quality of the Ponds discharge is intended to meet ambient water quality criteria.

Prior to recent and anticipated remedial activities, contaminated groundwater underlying the Ponds also discharged to the Clark Fork River via the Mill-Willow Bypass. Remedial activities that are presently underway to close the inactive Pond 1, and complete the reconstruction of the Mill-Willow Bypass, are intended to substantially reduce the discharge of contaminated groundwater underneath the Ponds to the Mill-Willow Bypass. Contaminated groundwater that formerly discharged to the Bypass will be collected and pumped back through the Ponds for treatment.

Table 2-16
Concentrations of Hazardous Substances in the Warm Springs Pond 2 Discharge
(Montana total recoverable concentrations in ppb)

Year	Cd		Cu		Pb		Zn	
	Range	Median	Range	Median	Range	Median	Range	Median
1983	NA	NA	< 10 - 190	35	NA	NA	20 - 260	90
1984	NA	NA	< 10 - 120	20	NA	NA	20 - 470	120
1985	NA	NA	< 10 - 100	30	NA	NA	15 - 495	132
1986	NA	NA	< 10 - 160	30	NA	NA	19 - 693	54
1987	NA	NA	< 10 - 40	20	NA	NA	7 - 191	43
1988	< 0.2 - 0.3	< 0.2	3 - 30	10	< 1 - 4	< 1	6 - 156	51
1989	< 0.2 - 0.2	< 0.2	7 - 210	20	< 1 - 55	2	10 - 576	58
1990	< 0.2 - 0.4	< 0.2	6 - 57	16	< 1 - 10	1	4 - 115	40
1991	< 0.2 - 0.9	0.4	16 - 49	24	1 - 52	4	43 - 118	61
1992	.1 - 3.1	1.0	9 - 338	37	1 - 40	6	16 - 484	91
1993	< .1 - 30.2	1.0	14 - 554	43	< 1 - 24	5	< 8 - 1551	96
1994[1]	< 0.1 - 0.8	0.4	8 - 33	27	< 1 - 5	3	< 4 - 170	41
Acute criterion[2]	8.6		34.1		197.3		210.6	
Chronic criterion[2]	2.0		21.4		7.7		190.7	

NA = Not analyzed.

1 Data available through October.
2 Criteria based on a hardness of 200 mg/l.

Source: STORET (1983 - 1991); ARCO (1992 - 1994).

Numerous seepages containing arsenic, copper, lead, and zinc from the Warm Springs Ponds directly to the Clark Fork River and Mill and Willow Creeks have also been documented over the years (Spindler, 1971; Anaconda Company, 1972).

2.3.2 Anaconda Area Waste Deposits

Warm Springs Creek flows approximately three miles through the Old Works Operable Unit (PTI, 1991) before joining the Clark Fork River. Tailings and other wastes associated with the operation of the Old Works were placed along the Warm Springs Creek channel. Waste deposits and sources described in the Old Works Engineering Evaluation/Cost Analysis (EE/CA) Preliminary Site Characterization Information report (PTI, 1991) include Waste Piles 1-8, Old Works structural area, heap roast slag, floodplain wastes, red sands, and waste ponds. These source areas all contain elevated concentrations of hazardous substances (Table 2-17).

Waste materials along Warm Springs Creek were evaluated during the Anaconda Smelter RI/FS (Tetra Tech, 1987) and the Old Works EE/CA (PTI, 1991). Various wastes, including jig tailings, mixed slag, brick rubble, urban waste, and debris were deposited in the Warm Springs Creek floodplain during the operating period of the Old Works (PTI, 1991). These floodplain wastes total approximately 440,000 cubic yards (PTI, 1991). Other waste volumes include approximately 298,390 cubic yards of heap roast slag, 606,700 cubic yards of Red Sands, and 8,050 cubic yards of material in the Waste Ponds. These waste deposits contain elevated concentrations of hazardous substances (Table 2-17).

Hydraulic modeling of Warm Springs Creek conducted for the Old Works EE/CA data summary report indicated that erosion of hazardous substances from the Red Sands area is predicted to occur during medium to high flows. In addition, backwater flooding over tailings deposits located upstream of the city dump road bridge is predicted during a 100 year flood. Exposed tailings also occur on or behind streambank levees. PTI (1991) concluded, "the location of these waste deposits adjacent to the stream and levels of the predicted 100 year flood indicate that erosion and transport may occur during very high flows." Elevated concentrations of hazardous substances have been documented in Warm Springs Creek downstream of the Old Works area (Ingman and Kerr, 1990). ESE, Inc. (1991) measured exceedences of copper and lead criteria in Warm Springs Creek downstream of the Old Works area. Samples collected upstream did not exceed criteria.

Recent and ongoing remedial activities include the construction of runoff detention basins at the base of several Old Works drainages, capping of floodplain tailings, and reconstruction of stream channel levees. Completion of remedial activities will substantially reduce, and may eliminate, releases from waste sources that were historically important sources to the Clark Fork River.

Table 2-17
Hazardous Substances in Old Works Area Waste Deposits
(concentrations in mg/kg)[1]

Material Description	Statistical Parameter	As	Cd	Cu	Pb	Zn
Waste Piles 1-8,[2] all samples	Arithmetic mean	1,018	2.4	7,791	185.1	532
	Maximum	8,110	11.2	32,100	990	1,660
	Minimum	4.2	0.4	22.2	8.4	51
Upper Works structural area,[2] all samples	Arithmetic mean	445.3	7.0	5,208	243.1	3,416
	Maximum	1,340	20	19,800	1,740	39,800
	Minimum	26.1	0.85	35.9	8.5	25.6
Heap Roast Slag[2] all samples	Arithmetic mean	759.3	3	8,212	321.7	5406
	Maximum	7,120	18.8	59,200	737	15,000
	Minimum	6.7	0.6	878	5	131
Heap Roast Slag[3] all samples	Arithmetic mean	958.5	13.1	6,550	1,008	17,750
	Maximum	1,007	13.4	7,000	1,030	18,100
	Minimum	910	12.8	6,100	985	17,400
Floodplain[2] all samples	Arithmetic mean	1,084	5.4	3,093	287.4	908
	Maximum	7,100	29	25,000	2,900	19,000
	Minimum	1.9	0.6	30	5	22
Red Sands[3] all samples	Arithmetic mean	1,685	10.5	2,665	455	3,530
	Maximum	2,170	13.3	3,170	618	4,640
	Minimum	1,200	7.7	2,160	292	2,420
Waste Ponds[2] all samples	Arithmetic mean	3,220	6.9	3,720	1,055	617
	Maximum	4,750	8.4	5,450	1,690	882
	Minimum	1,850	4.8	2,540	616	378

1 Source: PTI, 1991.
2 PTI, 1990, as cited in PTI, 1991.
3 Tetra Tech, 1987, as cited in PTI, 1991.

2.3.3 Opportunity Ponds

The Opportunity Ponds contain approximately 435,000,000 cubic yards of tailings generated by the Anaconda Smelter (Tetra Tech, 1987). Concentrations of hazardous substances in the Opportunity Ponds were quantified during the Anaconda Smelter RI/FS, and are summarized by Tetra Tech (1987) (Table 2-18). Hazardous substances are released to the underlying groundwater aquifer, resulting in a plume containing elevated concentrations of hazardous substances. Contaminated groundwater, in turn, discharges to several drains which border the Opportunity Ponds. These drains transport the groundwater discharge to Warm Springs Creek (North Drain Ditch) and to Warm Springs Pond 3 (North and South Opportunity Ponds

Table 2-18
Hazardous Substances in the Opportunity Ponds
(average concentrations in mg/kg)[1]

Location in Opportunity Ponds	As	Cd	Cu	Pb	Zn
Cell A[2]	370	8.2	2,200	600	1,490
Cell B1[2]	NA	5.4	1,530	440	962
Cell B1[3]	NA	NA	1,760	775	1,250
Cell B2[2]	147	3.6	1,790	380	1,080
Cell B2[3]	NA	NA	2,420	535	1,360
Cell C1[2]	216	5.2	1,970	380	1,570
Cell C1[3]	NA	NA	2,910	890	1,750
Cell C2[2]	238	10.3	2,320	380	960
Cell C2[3]	NA	NA	2,100	310	840
Cell D2[2]	61	< 2	1,170	170	700
Cell D2[3]	NA	NA	1,480	265	560
Various cells[4]	396	14.7	2,353	302	738

NA = Not analyzed.

1 Tetra Tech, 1987.
2 Tetra Tech, 1986, as cited in Tetra Tech, 1987.
3 Anaconda Minerals Company, 1981, as cited in Tetra Tech, 1987.
4 Lipton et. al., 1995.

Decant Ditches). Metals concentrations in the discharges to the Warm Springs Pond 3 were characterized in the Warm Springs Ponds Operable Unit Feasibility Study (MDHES and CH_2M Hill, 1989).

The North and South Opportunity Ponds discharges, with average flows of 1.3 and 0.97 cfs, respectively, transport hazardous substances from the Opportunity Ponds to Warm Springs Pond 3 (Table 2-19).

2.3.4 Riverside Tailings

Riverside tailings occur in the Warm Springs Ponds area and along the upper Clark Fork River, mainly upstream of Deer Lodge (Figure 2-4). Tailings deposits in the Warm Springs Ponds area were characterized in the Warm Springs Ponds Operable Unit Feasibility Study (MDHES and CH_2M Hill, 1989) (Table 2-20). Tailings deposits and contaminated soils a short distance downstream of Warm Springs Pond 1 are scheduled for removal as part of the

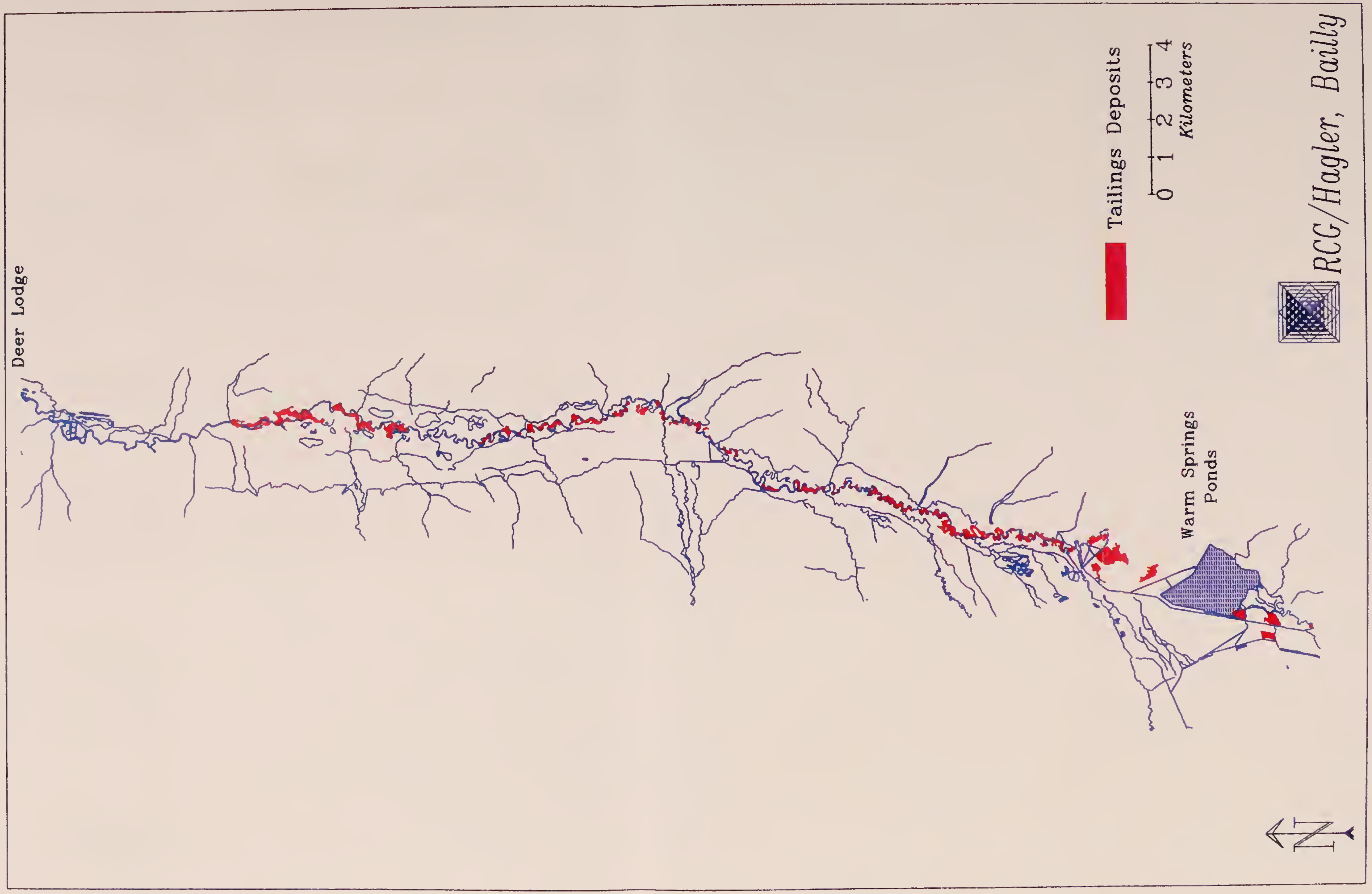

Figure 2-4. Floodplain Tailings Deposits, the Clark Fork River (Warm Springs Ponds to Deer Lodge).

Table 2-19
Hazardous Substances in the Opportunity Ponds Discharges
(concentrations in µg/l total)[1,2]

Discharge	As	Cd	Cu	Pb	Zn
North Opportunity Ponds discharge					
Maximum	19	0.6	100	192	1,680
Minimum	NA	NA	NA	NA	35
Average	4	0.1	310	16	198
South Opportunity Ponds discharge					
Maximum	25	0.3	65	129	632
Minimum	NA	NA	NA	NA	63
Average	10	NA	27	11	288

1 MDHES and CH_2M Hill, 1989.
2 NA = parameter not analyzed.

Table 2-20
Hazardous Substances in Tailings and Floodplain
Sediments of the Warm Springs Ponds Area and the Mill-Willow Bypass
(concentrations in mg/kg dry weight)

Location	As	Cd	Cu	Pb	Zn
Above Pond 3 and below Pond[1]	593	19.1	18,147	394	5,223
Mill-Willow Bypass[1]					
All sediments	121	22	3,713	215	4,258
Metallic salts	NM	NM	19,680	NM	21,266
Baseline[2]	7	0.22	20	15.4	56.5

NM = Not measured.

1 MDHES and CH_2M Hill, 1989.
2 See Chapter 3.0.

Pond 1 closure. Tailings in the Mill-Willow Bypass, which were removed during reconstruction of the Bypass beginning in 1990, most likely originated from outflows of the Opportunity Ponds and from tailings transported and deposited by Silver Bow Creek during high flows (MDHES and CH_2M Hill, 1989). Before reconstruction of the Bypass, exposed tailings were sources of hazardous substances to surface water during high streamflows or by precipitation-induced runoff. During extended dry periods, highly soluble blue- and green-colored salts of copper and zinc formed by evaporation of soil moisture on tailings deposits. Rapid solubilization of these salts during high-intensity precipitation events was responsible for several fish kills that occurred in the upper Clark Fork River in the 1980s. Numerous studies have attempted to quantify the extent of floodplain contamination. An estimated 920,000 cubic yards (704,000 cubic meters) of tailings cover 678 acres (275 ha) in the upper 10 km (6.2 miles) of the Clark Fork River floodplain (Nimick, 1990). Mixtures of cleaner fluvial sediments have been deposited on top of tailings, and tailings are continually cycled back and forth between the channel and the floodplain. An estimated two million cubic meters (2.5 million cubic yards) of contaminated sediment have been deposited on the Clark Fork River floodplain (J.N. Moore, University of Montana, *pers. comm.*, as cited in Axtmann and Luoma, 1991). One study, using existing soils maps and aerial photographs, estimated that 9,000 acres of floodplain soils have been contaminated with hazardous substances (CH_2M Hill et al., 1991). Additional acreage has been exposed to hazardous substances via irrigation with contaminated river water. Hazardous substance concentrations in tailings and floodplain sediments of the Clark Fork River are presented in Table 2-21.

2.3.5 Discharges from the Anaconda Smelter

The Anaconda Smelter was constructed in 1902 and operated until 1980. Emissions from the Anaconda Smelter stack have contaminated a large area surrounding Anaconda with the hazardous substances arsenic, cadmium, copper, lead, and zinc. Metals from soils contaminated by stack emissions are transported to the Clark Fork River by Mill Creek and Willow Creek via the Mill-Willow Bypass. Exceedences of aquatic life criteria in Willow Creek (cadmium, copper, and lead) and Mill Creek (cadmium and lead) were documented during high-flow sampling in May 1991 (ESE, Inc., 1991). Tetra Tech (1987) concluded that declining water quality in Mill Creek, which flows less than one mile from Smelter Hill, was likely caused by runoff from contaminated soils. Criteria exceedences in other streams are also likely related to runoff from soils contaminated by historic stack emissions. CDM (1994) described exceedences of ambient water quality criteria for cadmium, copper, lead and/or zinc in Warm Springs Creek, Mill Creek, Willow Creek and Lost Creek, which are all tributaries to the Clark Fork River.

Table 2-21
Hazardous Substances in Tailings and Floodplain Sediments of the Clark Fork River
(concentrations in mg/kg)

Location on the Clark Fork River	As	Cd	Cu	Pb	Zn	(n)
Below Warm Springs Ponds extending 10 km north[1]	769	3.64	4,532	712	1,839	83
North of Warm Springs Ponds[2]	600	5.7	3,662	547.3	2,206	67
Warm Springs Ponds to Deer Lodge[3]	634	8.8	1,760	461	1,160	8
Warm Springs Ponds to Drummond[4]	459	NA	3,328	394	1,834	140
Warm Springs Ponds to Turah[5]	NA	9.3	1,147	164	2,529	16
North of Deer Lodge[6]	176	5.0	1,630	NA	NA	40
Deer Lodge to Drummond[3]	610	8.4	1,090	398	1,120	9
Drummond to Milltown[3]	116	10	783	87	2,660	9

NA = Not analyzed.

1 Nimick, 1990.
2 Brooks, 1988.
3 Moore, 1985.
4 CH_2M Hill et. al., 1991.
5 Axtmann and Luoma, 1991.
6 Rice and Ray, 1984.

2.3.6 Pathways of Hazardous Substances from Sources to the Clark Fork River

Pathways by which hazardous substances migrate to the Clark Fork River are groundwater, surface water, and sediments. Migration of hazardous substances by the discharge of contaminated groundwater has been documented by numerous investigators, as discussed in Lipton et. al. (1995), Chapter 4.0. Surface water acts as a pathway to surface water by way of runoff over waste materials, and by way of riverine transport (surface water in upstream reaches moving to downstream reaches). The surface water pathway is discussed in more detail in Lipton et. al. (1995), Chapter 4.0. Sediments and associated wastes have migrated from the Butte and Anaconda areas by way of Silver Bow Creek to reaches of the Clark Fork River downstream. This is further discussed in Lipton et. al. (1995), Chapter 3.0.

2.4 SUMMARY

In summary, numerous sources release hazardous substances into the aquatic ecosystem of Silver Bow Creek and the Clark Fork River. These releases from mining and mineral processing in Butte and Anaconda have been continuous and ongoing since the onset of large-scale copper mining and mineral processing in Butte in approximately 1882.

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3.0 SEDIMENTS

3.1 INTRODUCTION

This chapter, together with the Bed Sediment Sampling and Chemical Analysis Report prepared as part of the Assessment (Essig and Moore, 1992), demonstrates that concentrations of hazardous substances in streambed sediments in Silver Bow Creek, the Clark Fork River, and the Warm Springs Ponds greatly exceed baseline concentrations. These contaminated streambed sediments serve as a principal exposure pathway to surface water and aquatic benthic macroinvertebrates, which in turn are an exposure pathway to fish. This chapter is organized as follows: Section 3.2 provides a brief overview and description of exposed areas. Section 3.3 compares of concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River to baseline conditions and to sediment toxicity thresholds. Section 3.4 compares the relative contributions of hazardous substances from tributaries to the Clark Fork River to those from Silver Bow Creek. Section 3.5 compares concentrations of hazardous substances in Silver Bow Creek and Clark Fork River to corresponding control sites used in the fish population studies (see Chapter 6.0). Finally, Section 3.6 identifies pathways of hazardous substances to Silver Bow Creek and the Clark Fork River.

3.2 DESCRIPTION OF EXPOSED AREAS

3.2.1 Silver Bow Creek

From its origin in Butte, Silver Bow Creek flows west and north a distance of approximately 37 kilometers (23 miles) to its discharge at Warm Springs Ponds (Canonie, 1992). Its average gradient is approximately 0.5%, and its average width is approximately 4.7 meters (15.4 ft) (Chadwick et al., 1986).

The Berkeley Pit, Yankee Doodle Tailings Pond, and associated mining facilities have obliterated a portion of the original Silver Bow Creek channel in Butte (MultiTech, 1987a). The channel from the Weed Concentrator in Butte to Blacktail Creek was reconfigured as the Metro Storm Drain (MSD) in the early 1930s by realigning and filling in the original Silver Bow Creek channel (MultiTech, 1987a). Today, the MSD carries little or no flow, except during storm events or snowmelt runoff (MultiTech, 1987a). The majority of headwater flow in Silver Bow Creek now originates as inflow from Blacktail Creek (Canonie, 1991).

The only perennial "tributaries" to Silver Bow Creek are the Butte Metro Wastewater Treatment Plant (WWTP) discharge, Browns Gulch, German Gulch, and the Silver Lake pipeline discharge near Ramsay. Ephemeral tributaries include Missoula Gulch, Whiskey Gulch, Gimlet Gulch, and Sand Creek (MultiTech, 1987a).

Groundwater contributes a significant portion of the flow to Silver Bow Creek in the Butte area (Canonie, 1992).

3.2.2 Warm Springs Ponds

Warm Springs Ponds are settling and treatment ponds that were constructed near the confluence of Silver Bow Creek and Warm Springs Creek to collect tailings and other mine wastes being carried downstream by Silver Bow Creek (U.S. EPA, 1990). Ponds 1 and 2 were constructed prior to 1920 by the Anaconda Copper Company (MDHES and CH_2M Hill, 1989). Pond 3 was constructed between 1954 and 1959 (MDHES and CH_2M Hill, 1989). Currently, Silver Bow Creek enters Pond 3 from the south, and water is routed from Pond 3 into Pond 2 by two decant towers and into nearby wildlife ponds via siphons (MultiTech, 1987a). The discharge from Pond 2 joins with the Mill-Willow Bypass, which routes the combined flows of Mill and Willow Creeks around the pond system. Pond 1 is no longer used. The Clark Fork River begins at the confluence of Warm Springs Creek and the combined Mill-Willow Bypass and Pond 2 discharge, about one mile downstream of Warm Springs Ponds (Figure 3-1).

Lime (calcium hydroxide) has been added to pond inflows since 1959 on a seasonal or streamflow basis to aid in precipitating dissolved metals (Johnson and Schmidt, 1988). Submerged sediments range in thickness from less than one meter (3 feet) to over 6 meters (18 feet) (U.S. EPA, 1990). Collectively, the ponds contain an estimated 15 million cubic meters (19 million cubic yards) of tailings and sediments contaminated with arsenic, cadmium, copper, lead, zinc, and other heavy metals (Hydrometrics, 1983; MultiTech, 1987b). These tailings and sediments are typically fine to coarse-grained sand (U.S. EPA, 1990).

3.2.3 Clark Fork River

The headwaters of the Clark Fork River are formed by the confluence of Warm Springs Creek with the combined flows of the Mill-Willow Bypass and the Warm Springs Pond 2 discharge (Figure 3-1). From this confluence to the Milltown Reservoir, a distance of approximately 195 kilometers (120 miles), the Clark Fork River is relatively shallow with an overall gradient of approximately 0.25% (Brook and Moore, 1988; Essig and Moore, 1992). Major tributaries in this reach include Little Blackfoot River, Flint Creek, and Rock Creek (see Figure 1-1).

Streamflow in the Clark Fork River increases downstream and varies seasonally. For the years 1985-1990, monthly mean streamflow ranged from approximately 30 cubic feet per second (cfs) in August to 191 cfs in May near Galen (approximately 8 kilometers (5 miles) from the headwaters just below the Warm Springs Ponds) and from 544 cfs in August to 2,200 cfs in May at Turah Bridge, a short distance upstream of Milltown (Lambing, 1991).

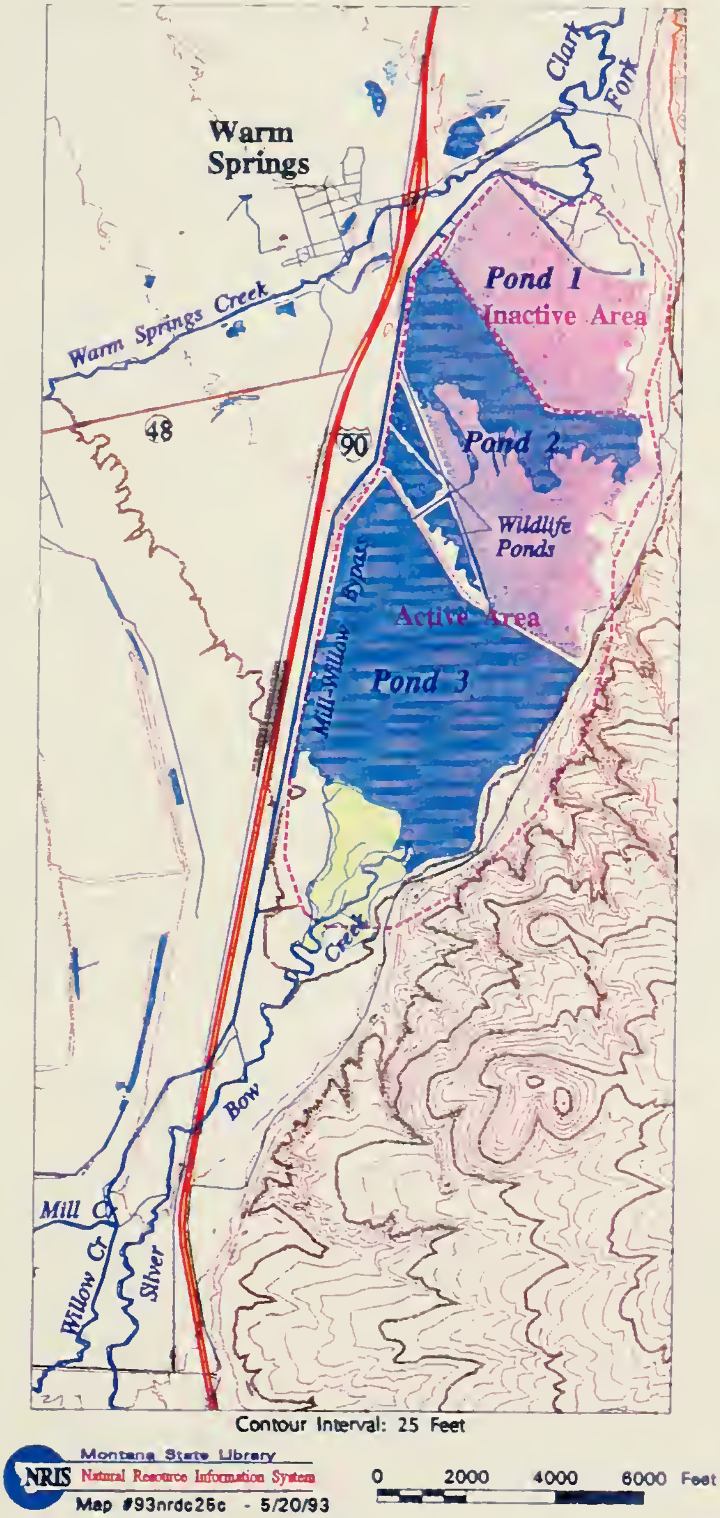

Figure 3-1. Warm Springs Ponds Area.

The Clark Fork River is a high-gradient system that carries large amounts of coarse sand during spring runoff and other high flows (Brook and Moore, 1988). Metals-laden tailings, deposited along floodplains over the last 100 years, contribute to this coarse fraction carried by the river (Brook and Moore, 1988; Johnson and Schmidt, 1988). The size, concentration, and loadings of suspended sediments depend on streamflow characteristics. Suspended sediment concentration, grain size, and loadings tend to increase as flow rates increase in the Clark Fork River, since higher energy flow can transport larger particles (ENSR, 1992; Lambing, 1991).

Bed sediments of the Clark Fork River are composed of particles of varying grain-sizes, from fine-grained to coarse-grained particles (Brook and Moore, 1988). The fine-grained portion of bed sediment (< 63 µm) is particularly important in determining sediment contamination from anthropogenic sources and in assessing sediment impacts to biota, as described below.

Fine-grained sediments represent sediment recently suspended in the river and carried downstream, and thus provide a strong basis for establishing anthropogenic contaminant sources (Essig and Moore, 1992). Fine-grained sediment analysis also provides a more reliable and less biased means of assessing sediment contamination than does bulk sediment analysis (Axtmann and Luoma, 1991). Finally, benthic macroinvertebrates are exposed to and can uptake contaminants from fine-grained sediments in depositional zones and micro-depositional habitats in a riverine environment such as the Clark Fork River (Essig and Moore, 1992; Luoma, 1992). Benthic macroinvertebrates ingest fine-grained sediments during feeding, and through digestion can accumulate hazardous substances from the sediments (Luoma, 1989; Gower and Darlington, 1990; Timmermans, 1993). The correlation of metals concentrations in macroinvertebrates with concentrations in fine-grained sediments from the Clark Fork River (see Chapter 5.0) also demonstrates the importance of fine-grained sediments to benthic macroinvertebrates (Axtmann and Luoma, 1991; Cain et al., 1992).

3.3 EXTENT OF SEDIMENT CONTAMINATION

3.3.1 Sediment Contamination in Silver Bow Creek

As a result of hazardous substance releases to Silver Bow Creek, sediments throughout the creek are contaminated with hazardous substances relative to baseline conditions.

Historical data to assess the baseline condition of Silver Bow Creek prior to hazardous substance releases are not available, because releases to Silver Bow Creek have occurred since the late 1800s. Therefore, streams in or near the Clark Fork River Basin that are comparable to Silver Bow Creek except for exposure to the hazardous substance releases were selected as control areas to represent baseline conditions. Control areas against which Silver Bow Creek bed sediment metals concentrations were compared are Gold Creek, Ruby River, and Rock Creek (Essig and Moore, 1992). Gold Creek and Rock Creek are tributaries to the

Clark Fork River downstream of Silver Bow Creek, and the Ruby River is located in a nearby drainage basin. All three control stream drainages are relatively unaffected by mining activities.

Median concentrations of arsenic, cadmium, copper, lead, and zinc in Silver Bow Creek fine sediments (< 63 µm) are compared to baseline conditions in Table 3-1. Figures 3-2 through 3-6 plot concentrations of hazardous substances as a function of downstream distance in Silver Bow Creek and the Clark Fork River relative to baseline conditions. Median copper sediment concentrations in Silver Bow Creek are approximately 400 times greater than baseline concentrations (Essig and Moore, 1992). Median concentrations of zinc are more than 150 times greater than baseline, and arsenic, cadmium, and lead are approximately 74, 115, and 115 times greater than baseline, respectively (Essig and Moore, 1992).

Table 3-1
Median Concentrations of Hazardous Substances in Fine Bed Sediments of Silver Bow Creek and Control Streams
(units in ppm dry weight)

	No. of Sites	Arsenic	Cadmium	Copper	Lead	Zinc
Silver Bow Creek	13	543	34.7	9,000	1,530	8,880
Baseline (Rock Creek, Gold Creek, Ruby River)	19	7.3	0.3	17.3	13.4	54.1

Source: Essig and Moore, 1992.

3.3.2 Sediment Contamination in Warm Springs Ponds

In the approximately 80 years since the first pond was constructed, an estimated 15 million cubic meters (19 million cubic yards) of mill tailings, mine waste rock, natural sediments, and precipitates have collected in the ponds (Hydrometrics, 1983). Table 3-2 presents mean arsenic and metals concentrations in bed sediments of the three ponds, along with baseline concentrations. Mean arsenic concentrations in the ponds exceed baseline conditions by roughly 40-80 times, copper concentrations exceed baseline by roughly 150-350 times, cadmium concentrations exceed baseline by roughly 45-850 times, and lead and zinc concentrations exceed baseline by roughly 15-45 and 40-300 times, respectively. These hazardous substances contained in pond sediments can be remobilized and serve as an ongoing source of hazardous substances to surface water and groundwater.

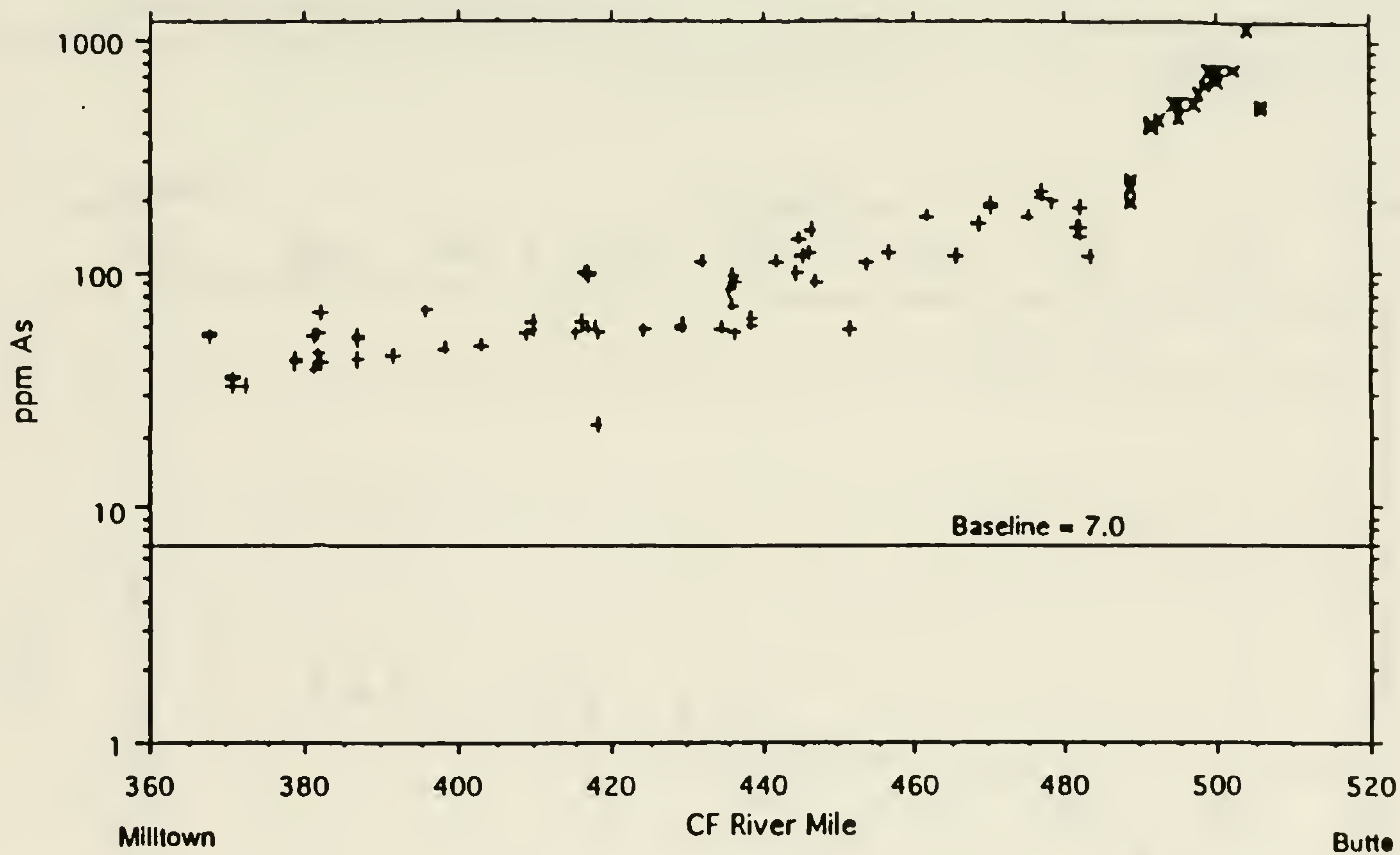

Figure 3-2. Sediment Arsenic Trend. Source: Essig and Moore, 1992.
(+ = Clark Fork River; × = Silver Bow Creek)

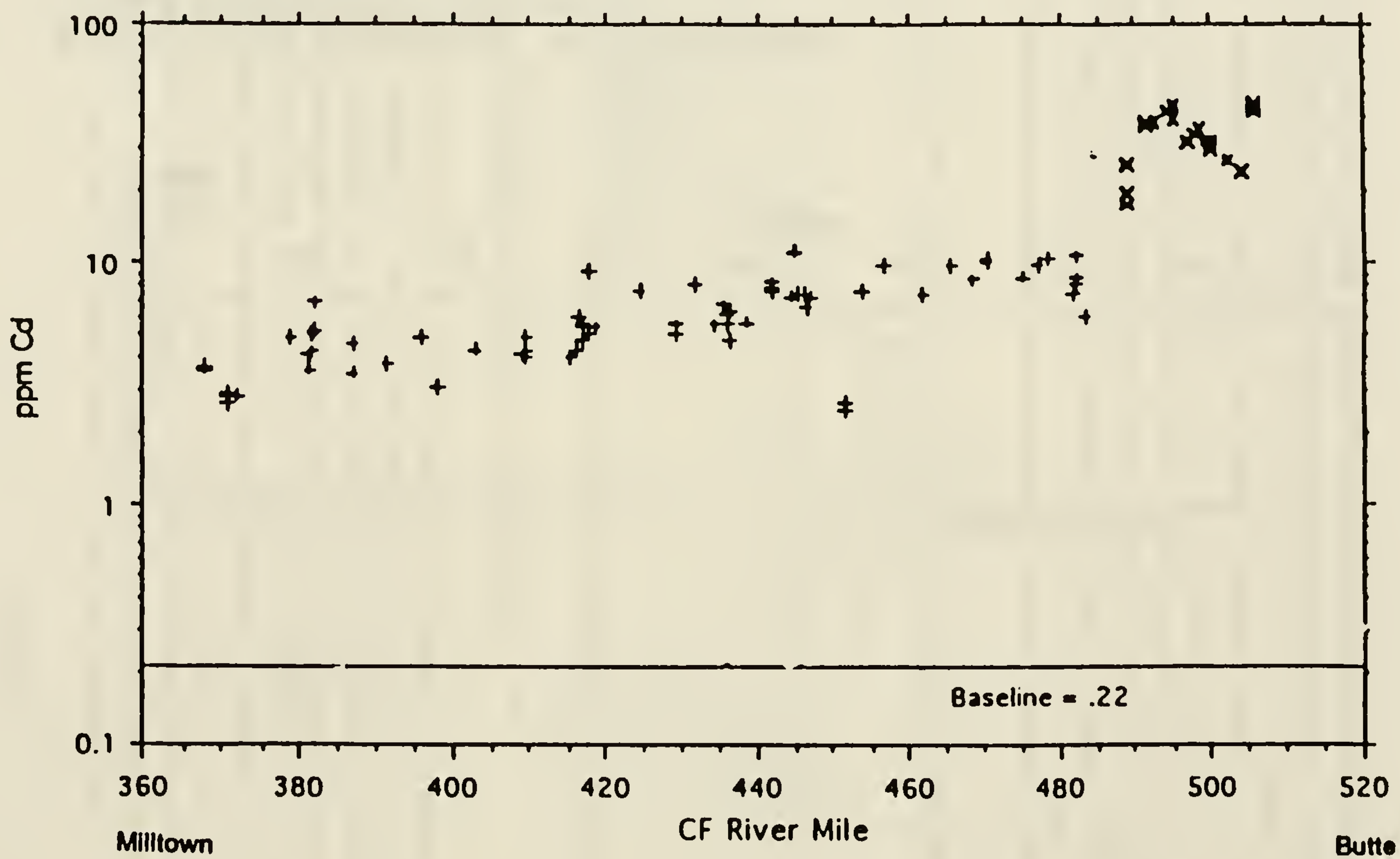

Figure 3-3. Sediment Cadmium Trend. Source: Essig and Moore, 1992.
(+ = Clark Fork River; × = Silver Bow Creek)

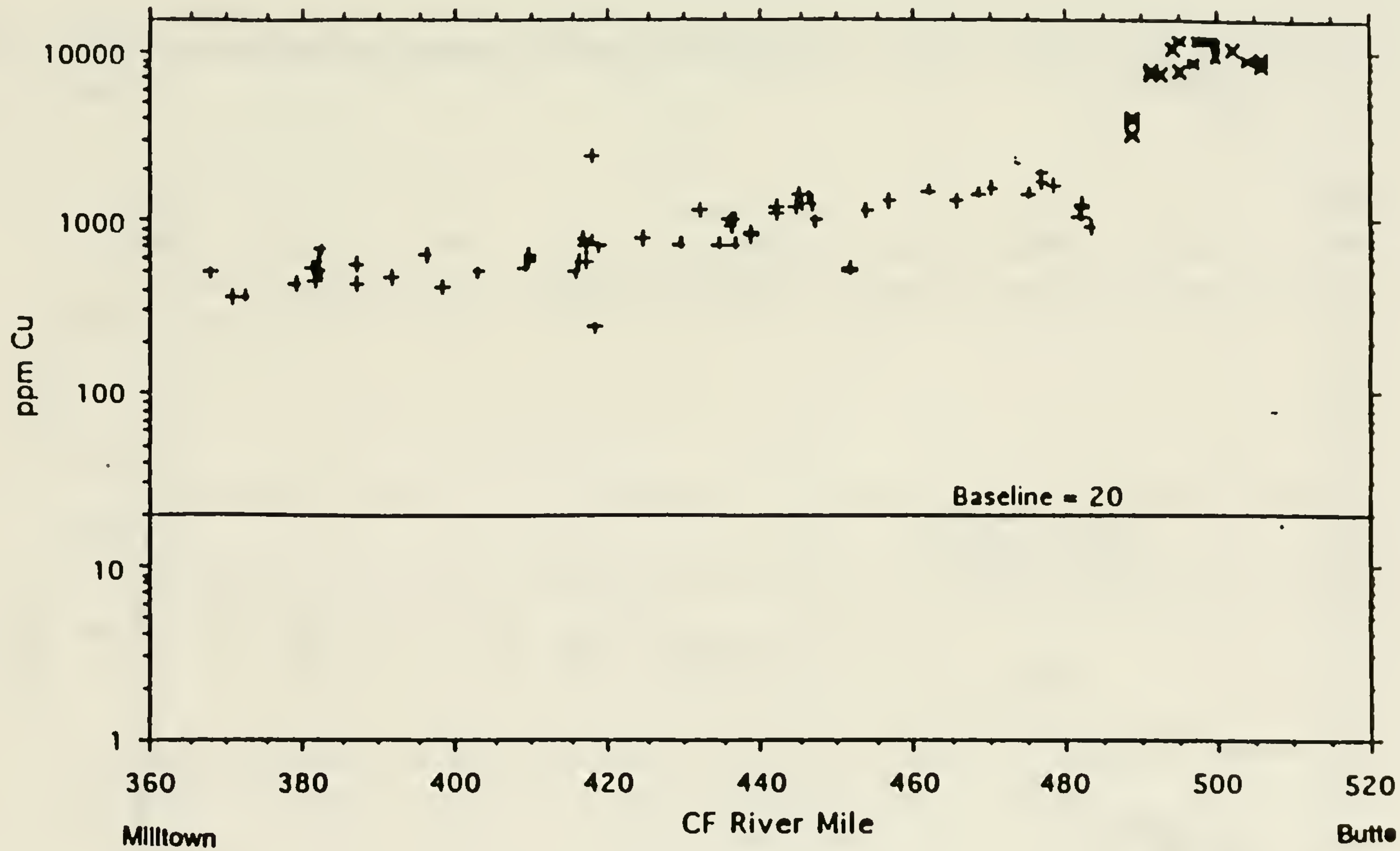

Figure 3-4. Sediment Copper Trend. Source: Essig and Moore, 1992.
(+ = Clark Fork River; x = Silver Bow Creek)

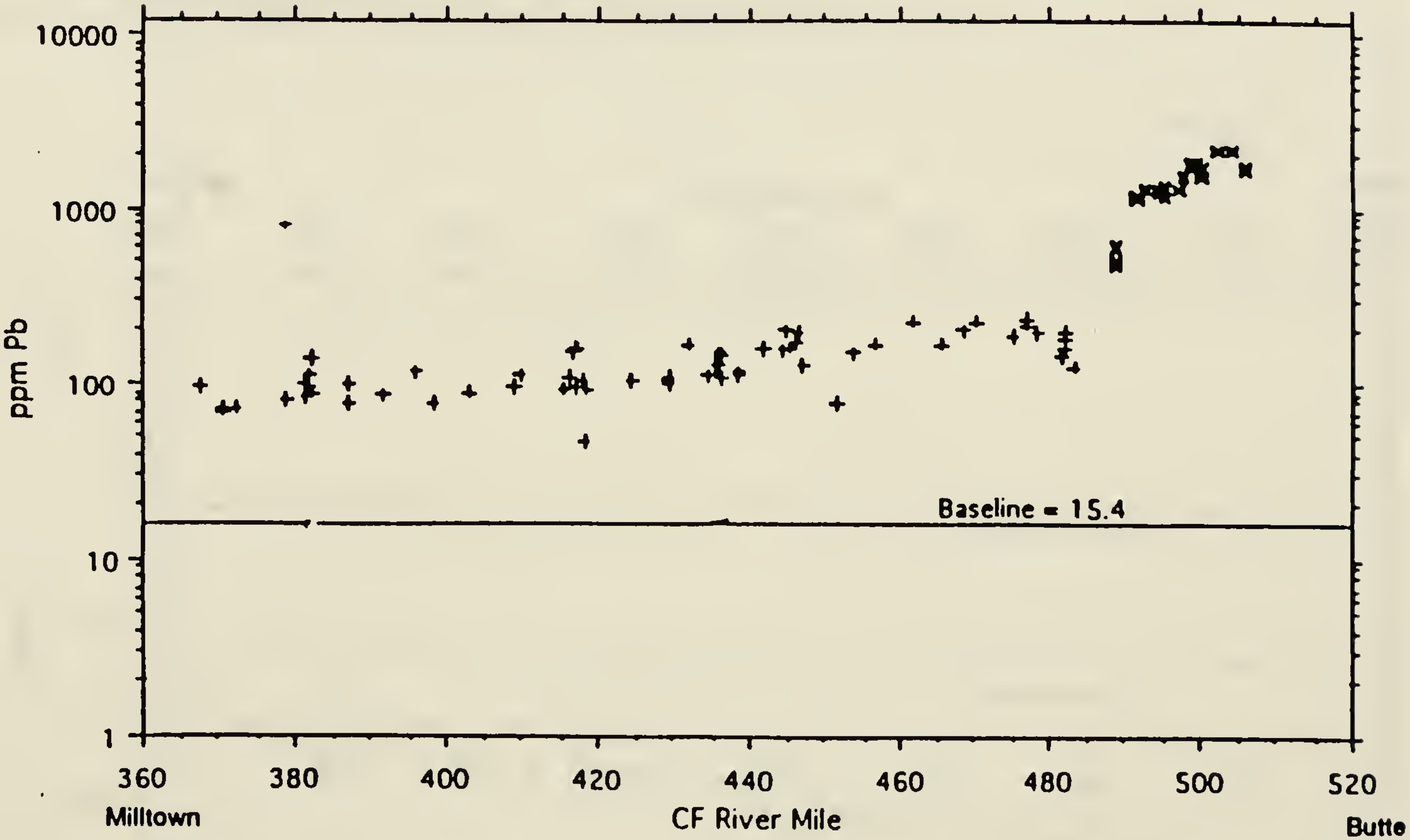

Figure 3-5. **Sediment Lead Trend.** Source: Essig and Moore, 1992.
(+ = Clark Fork River; x = Silver Bow Creek)

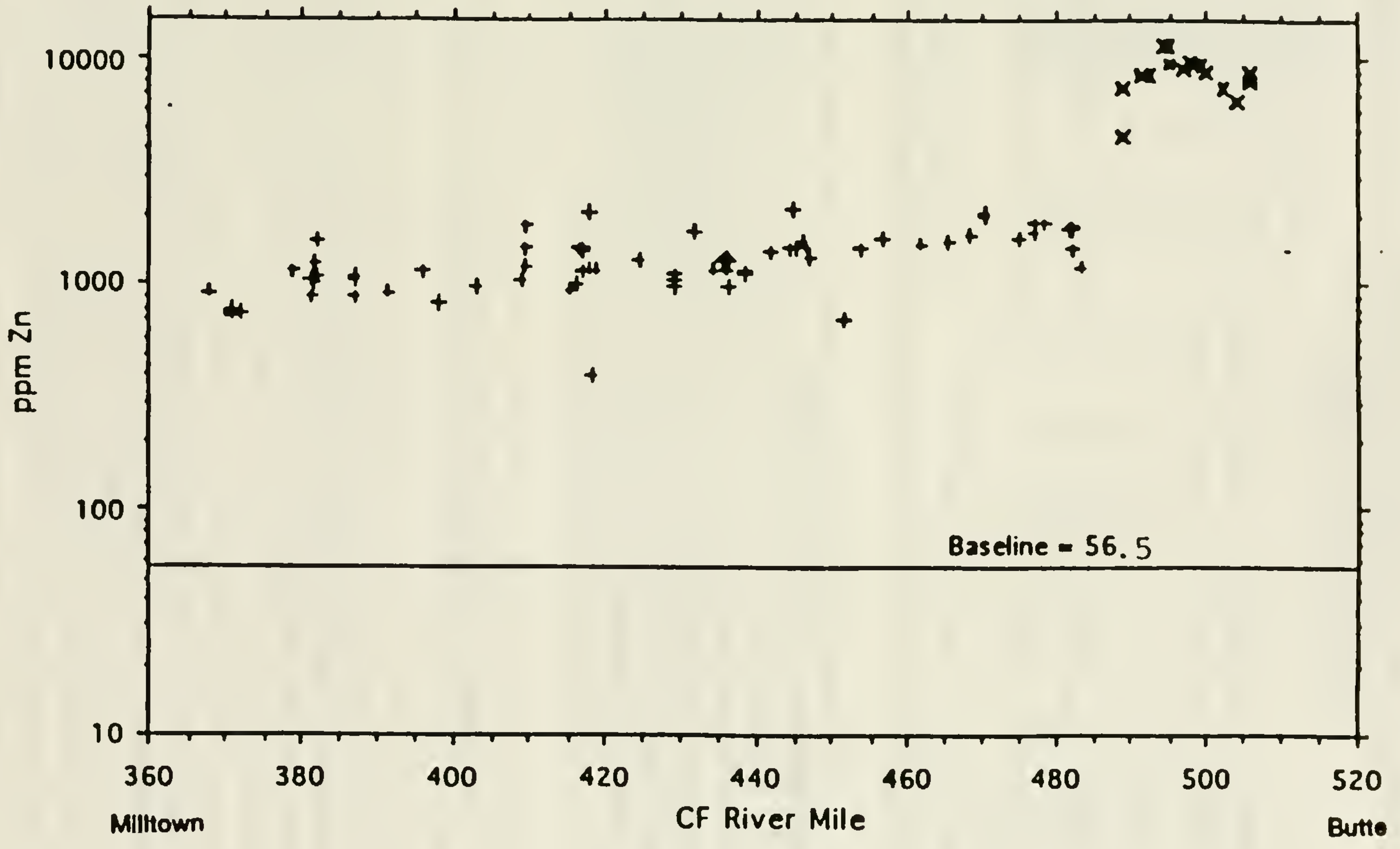

Figure 3-6. **Sediment Zinc Trend.** Source: Essig and Moore, 1992.
(+ = Clark Fork River; x = Silver Bow Creek)

Table 3-2
Mean Concentrations of Hazardous Substances in Warm Springs Ponds Bed Sediments (metals in ppm dry weight)

	Arsenic	Cadmium	Copper	Lead	Zinc
Pond 1[1]	408	10	2,886	670	2,212
Pond 2[2]	590	36	4,661	726	4,859
Pond 3[2]	301	195	7,015	252	17,318
Baseline[3]	7.0	0.22	20	15.4	56.5

1 U.S. EPA, 1992.
2 CH_2M Hill, 1988 as cited in Johnson and Schmidt, 1988.
3 Essig and Moore, 1992.

3.3.3 Sediment Contamination in the Clark Fork River

As a result of hazardous substance releases to and transport within the Clark Fork River, sediments throughout the river from its headwaters to at least as far downstream as the Milltown Reservoir are contaminated with hazardous substances at concentrations well above baseline. Figures 3-2 through 3-6 demonstrate a clear pattern of decreasing hazardous substance concentrations with downstream distance from sources in Butte.

As with Silver Bow Creek, no historical data are available to characterize pre-release conditions in the Clark Fork River. Baseline conditions were determined using the control streams described previously (Gold Creek, Ruby River, and Rock Creek).

Table 3-3 compares median fine-grained sediment concentrations of arsenic, cadmium, copper, lead, and zinc in control streams with those in three Clark Fork River reaches: Clark Fork River - Upper (headwaters to Garrison Junction); Clark Fork River - Middle (Garrison to Rattler Gulch near Bradman); and Clark Fork River - Lower (Rattler Gulch to Milltown Reservoir). Median copper concentrations in the lower, middle, and upper reaches of the Clark Fork River are 29, 45, and 75 times greater than baseline concentrations, respectively. Median cadmium concentrations are 14, 18, and 26 times greater than baseline in these reaches, whereas zinc concentrations are 19, 22, and 29 times greater than baseline. Median arsenic concentrations are 7, 9, and 19 times greater than baseline in the lower, middle, and upper these reaches. Essig and Moore (1992) contains a more detailed statistical characterization of this contamination.

Table 3-3
Median Concentrations of Hazardous Substances in Fine-grained Bed Sediment of the Clark Fork River (CFR) and Control Streams
(units in ppm dry weight)

	No. of Sites	Arsenic	Cadmium	Copper	Lead	Zinc
CFR — upper	19	142	7.7	1,302	176	1,573
CFR — middle	19	63.2	5.5	785	116	1,173
CFR — lower	17	50.3	4.3	502	93	1,020
Baseline	19	7.3	0.3	17.3	13.4	54.1

Source: Essig and Moore, 1992.

Other investigators have also documented highly elevated concentrations of hazardous substances in the Clark Fork River relative to baseline. Data collected by the USGS yearly from 1986 through 1993 confirm that Clark Fork River bed sediments are contaminated with hazardous substances at concentrations orders of magnitude greater than in Clark Fork River tributaries relatively unaffected by mining impacts (Axtmann and Luoma, 1991; Axtmann, 1994; Hornberger and Luoma, 1994; Lambing et al., 1994). Bed sediment data collected in 1991-1992 by Boggs (1994) also documents large-scale hazardous substance contamination in the Clark Fork River between Warm Springs Ponds and Milltown.

3.3.4 Comparison to Sediment Toxicity Threshold Concentrations

As a measure of the magnitude of contamination in Silver Bow Creek and Clark Fork River, sediment hazardous substance concentrations can be compared to toxicity threshold concentrations that have been developed to assess the potential for sediments to cause toxicity to benthic macroinvertebrates. Injury to benthic macroinvertebrates is addressed in more detail in Chapter 5.0.

Applicable sediment toxicity threshold concentrations have been developed by the National Oceanic and Atmospheric Administration (NOAA) and the Ontario Ministry of the Environment. NOAA has used data from their National Status and Trends Program, which monitors aquatic ecosystems across the country, to develop sediment threshold concentrations that indicate the likelihood for effects to benthic communities (Long and Morgan, 1991). One of these threshold values is termed the Apparent Effects Threshold (AET), which represents the concentration above which adverse effects to benthic organisms usually or always

occurred, based on NOAA's data. Although these AETs integrate data from across the country and from both salt and freshwater environments, they provide valuable "benchmark" information against which Silver Bow Creek and Clark Fork River sediments can be compared.

The Ontario Ministry of the Environment has also developed a set of sediment threshold concentrations for contaminants. Their thresholds are developed from field-based data on the relationship between sediment contaminant concentrations and observed effects on benthic communities in freshwater systems (Persaud et al., 1993). The Severe Effects Threshold (SET) represents the contaminant concentration in sediments at which "pronounced disturbance of the sediment-dwelling community can be expected", and is "the sediment concentration of a compound that would be detrimental to the majority of benthic species" (Persaud et al., 1991). The SET and the NOAA AET thus are thresholds for individual contaminants above which *major* impacts to benthic communities can be expected. NOAA AETs and Ontario SETs are presented in Table 3-4 for arsenic, cadmium, copper, lead, and zinc.

Table 3-4
NOAA's AETs and Ontario's SETs for Sediments

	NOAA Apparent Effects Threshold (AET) (mg/kg dry wt.)	Ontario's Severe Effects Threshold (SET) (mg/kg dry wt.)
Arsenic	50	33
Cadmium	5	10
Copper	300	110
Lead	300	250
Zinc	260	820

Figures 3-7 through 3-11 compare the concentration ranges for arsenic, cadmium, copper, lead, and zinc in Silver Bow Creek with those from control streams (Rock Creek, Ruby River, and Gold Creek) and with AETs and SETs. Two different Silver Bow Creek concentrations are plotted: concentrations in bulk, or total, sediments (PTI, 1989), and concentrations in fine-grained (< 63 μm) sediments (Essig and Moore, 1992).

These figures show that every Silver Bow Creek fine-grained sediment sample contained arsenic, cadmium, copper, lead, and zinc above both the AET and SET; median concentrations are orders of magnitude greater than AETs and SETs for these hazardous

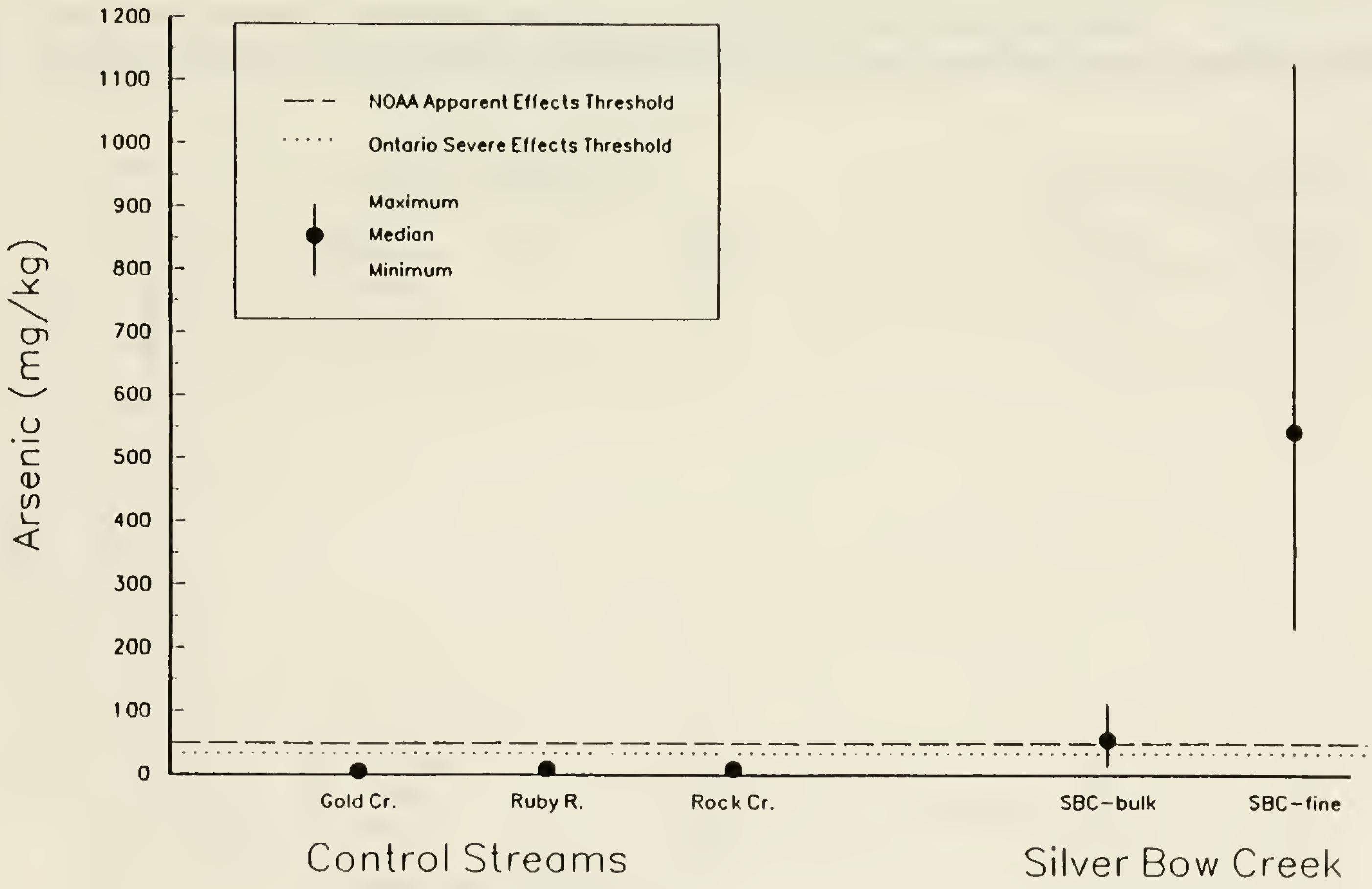

Figure 3-7. Median Arsenic Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared with Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

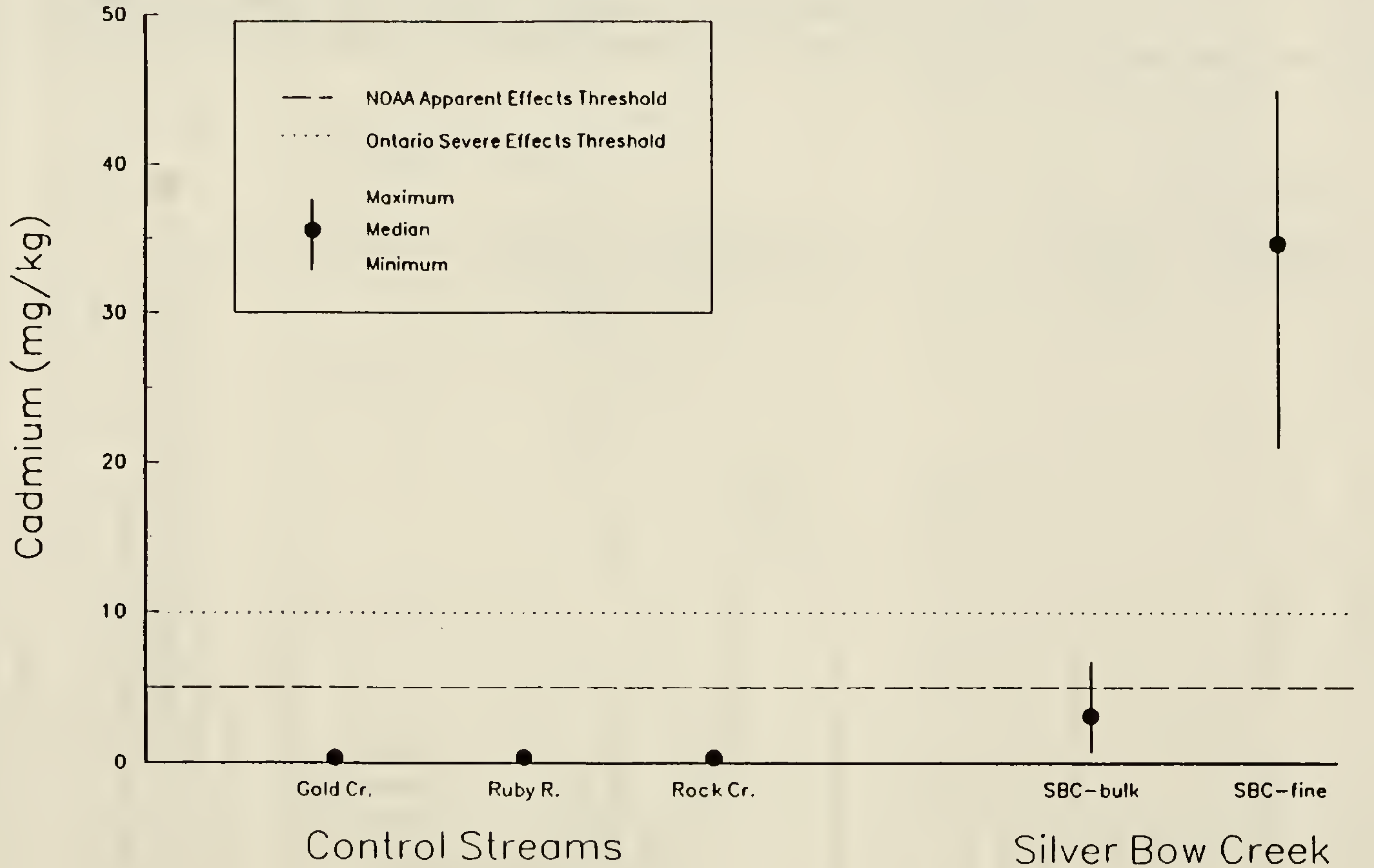

Figure 3-8. Median Cadmium Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared with Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

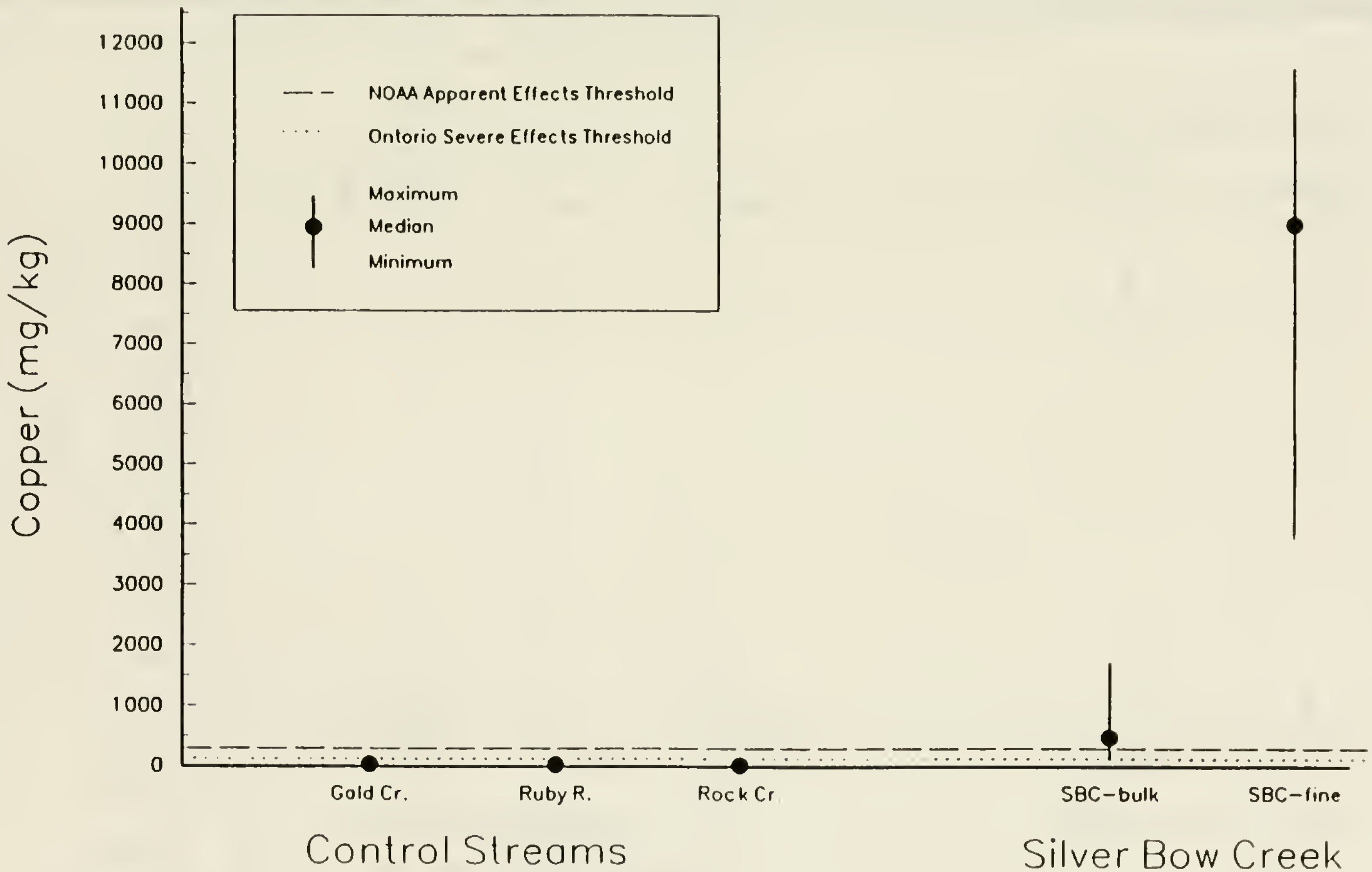

Figure 3-9. Median Copper Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared with Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

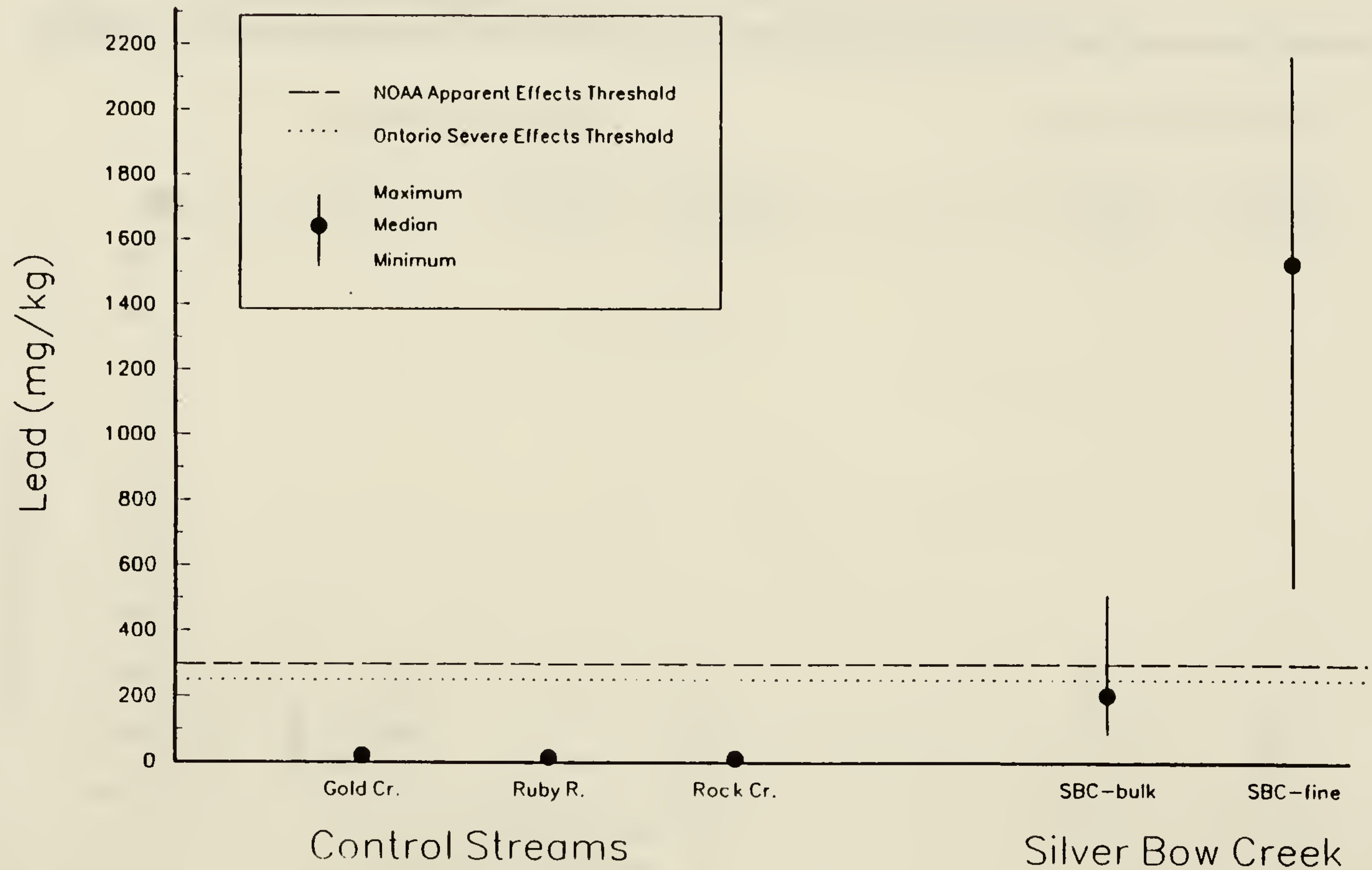

Figure 3-10. Median Lead Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared with Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

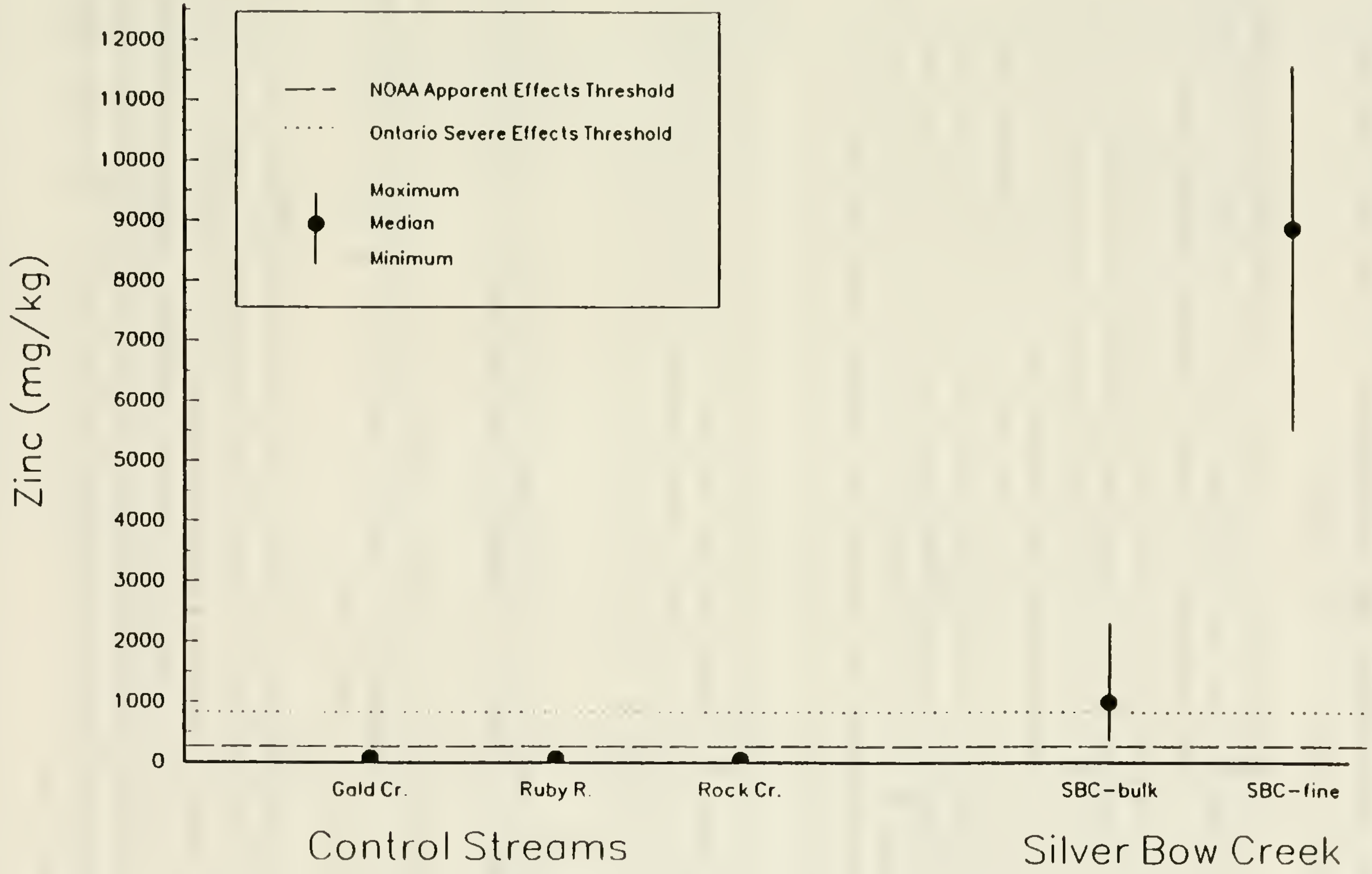

Figure 3-11. Median Zinc Bed Sediment Concentrations in Silver Bow Creek and Control Streams Compared with Sediment Threshold Concentrations. Sources: Essig and Moore, 1992; PTI, 1989.

substances. Median bulk concentrations of arsenic, copper, and zinc also exceed both the AET and SET. Although *median* bulk concentrations of cadmium and lead are below both thresholds, these hazardous substances have been measured in Silver Bow Creek bulk sediments at concentrations that exceed the thresholds.

Figures 3-12 through 3-16 compare median concentrations of arsenic, cadmium, copper, lead, and zinc in the Clark Fork River and control streams with AETs and SETs. Clark Fork River samples are grouped into upper (headwaters to Garrison Junction), middle (Garrison to Rattler Gulch near Bradman), and lower (Rattler Gulch to Milltown Reservoir) reaches. All measured arsenic concentrations in the upper and middle reaches exceed both the AET and the SET (Figure 3-12). In the lower reach, all arsenic concentrations exceeded the SET and most exceed the AET. All measured cadmium concentrations in the upper reach and most in the middle reach exceeded the AET, and some concentrations in the upper reach also exceeded the SET (Figure 3-13). As with Silver Bow Creek, all copper concentrations throughout the Clark Fork River exceeded both thresholds (Figure 3-14). Some lead concentrations measured in the upper reach exceed both the AET and the SET (Figure 3-15). All measured zinc concentrations from the upper and middle reaches, and nearly all concentrations in the lower reach, also exceed the zinc AET and SET (Figure 3-16).

These data indicate that bed sediments throughout Silver Bow Creek and the Clark Fork River from Warm Springs Ponds to Milltown contain hazardous substances at concentrations well above toxicity threshold levels. In contrast, no samples from control streams contained arsenic, cadmium, copper, lead, or zinc at concentrations above the thresholds.

3.4 LARGE-SCALE MINING AND MINERAL PROCESSING OPERATIONS IN BUTTE AND ANACONDA AS SOURCES OF SEDIMENT CONTAMINATION

The hazardous substances in the bed sediments of Silver Bow Creek, Warm Springs Ponds, and the Clark Fork River originated from numerous large-scale mining and mineral processing operations in the Butte and Anaconda areas.

Three primary factors establish that Silver Bow Creek, Warm Springs Ponds, and the Clark Fork River have been contaminated by large-scale mining operations in Butte and Anaconda: (1) the downstream decline in hazardous substance concentrations is indicative of an upstream source in Butte and Anaconda; (2) mining and mineral processing operations in Butte and Anaconda are known sources of hazardous substance releases; and (3) significant downstream transport of hazardous substances from sources has been documented. This section describes these factors in greater detail.

1. **The distribution of hazardous substances in bed sediments of the Clark Fork River from Warm Springs Ponds to the Milltown Reservoir exhibits**

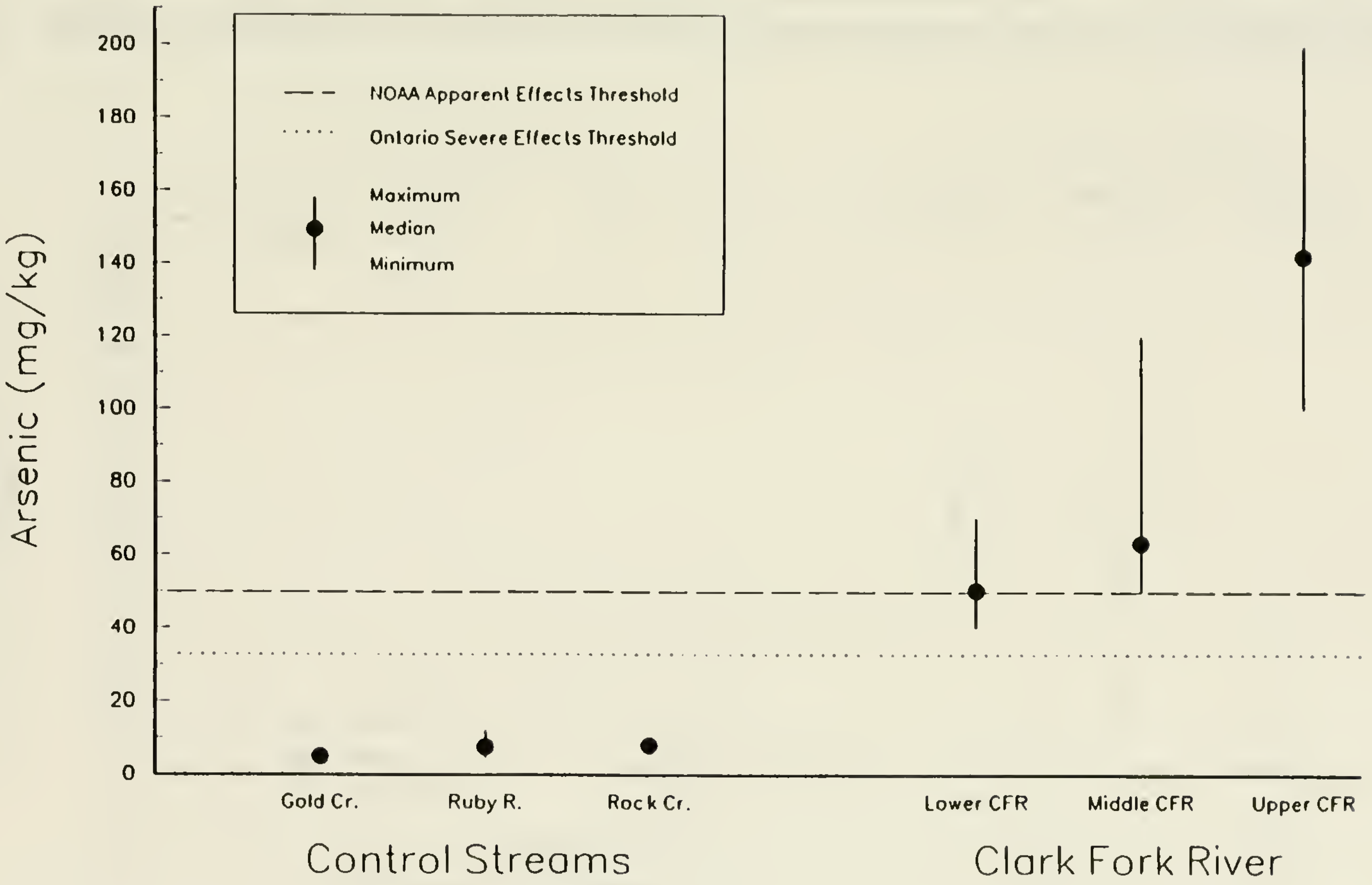

Figure 3-12. Median Concentrations of Arsenic in Clark Fork River and Control Stream Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

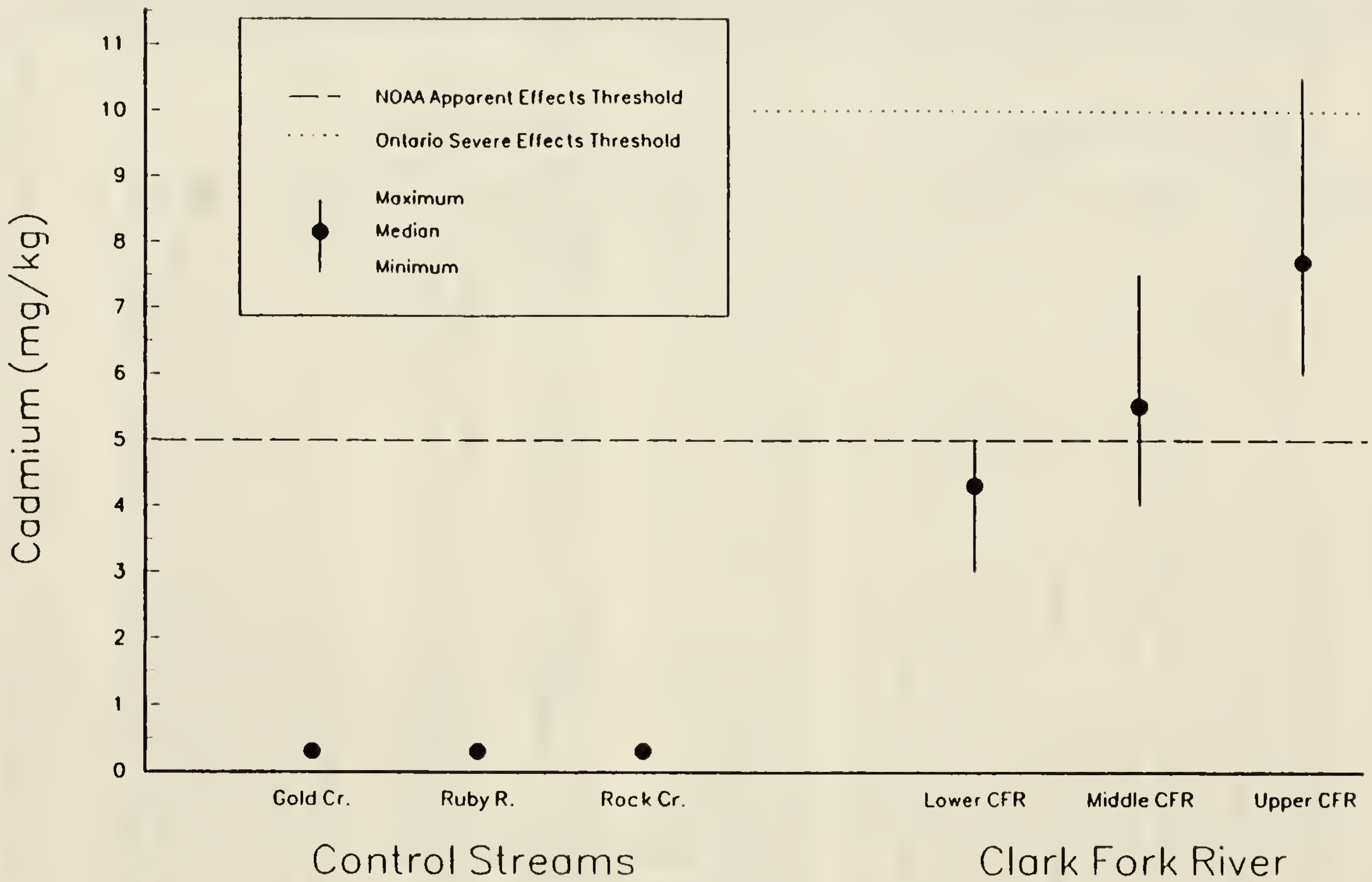

Figure 3-13. Median Concentrations of Cadmium in Clark Fork River and Control Stream Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

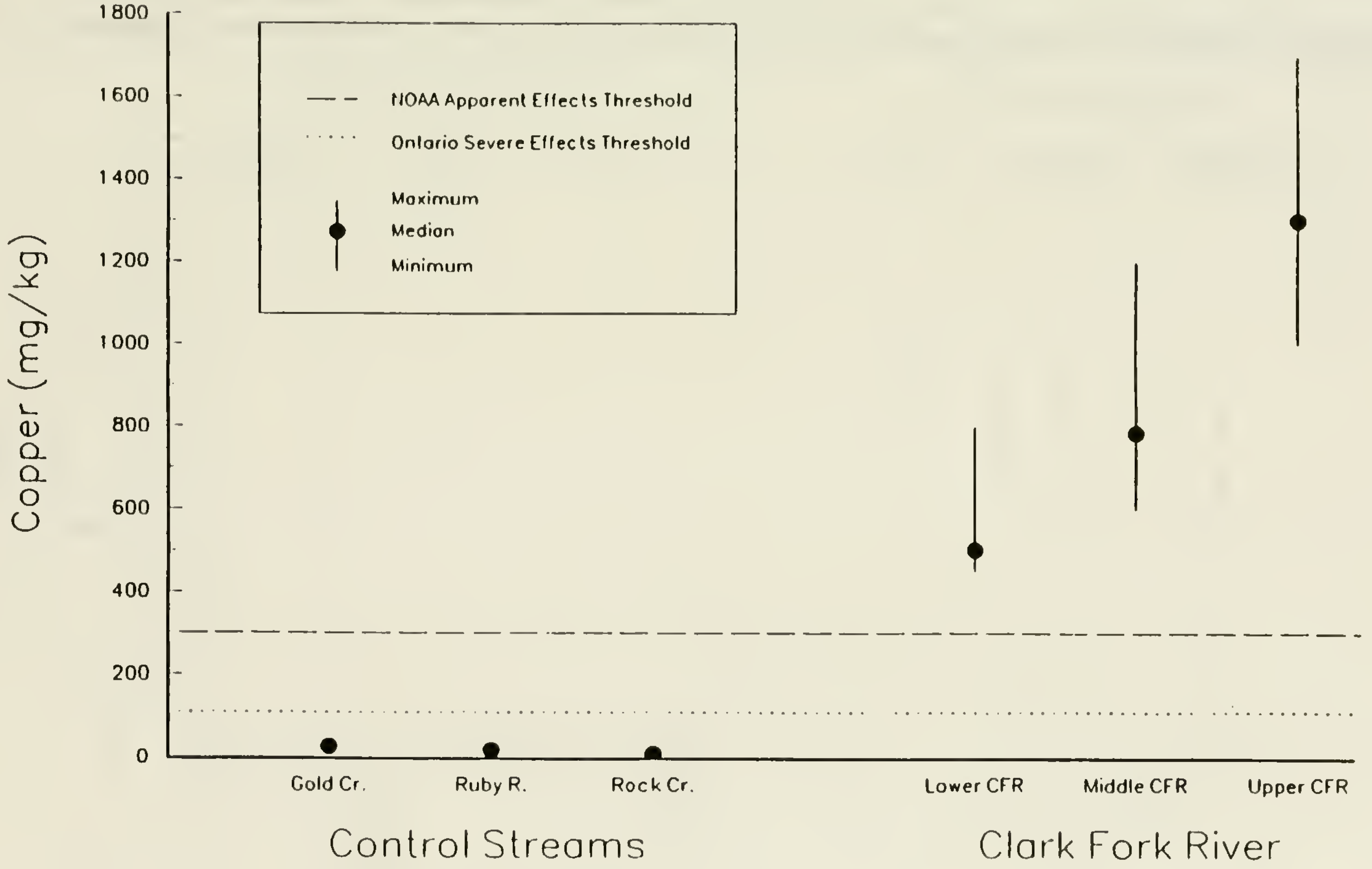

Figure 3-14. Median Concentrations of Copper in Clark Fork River and Control Stream Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

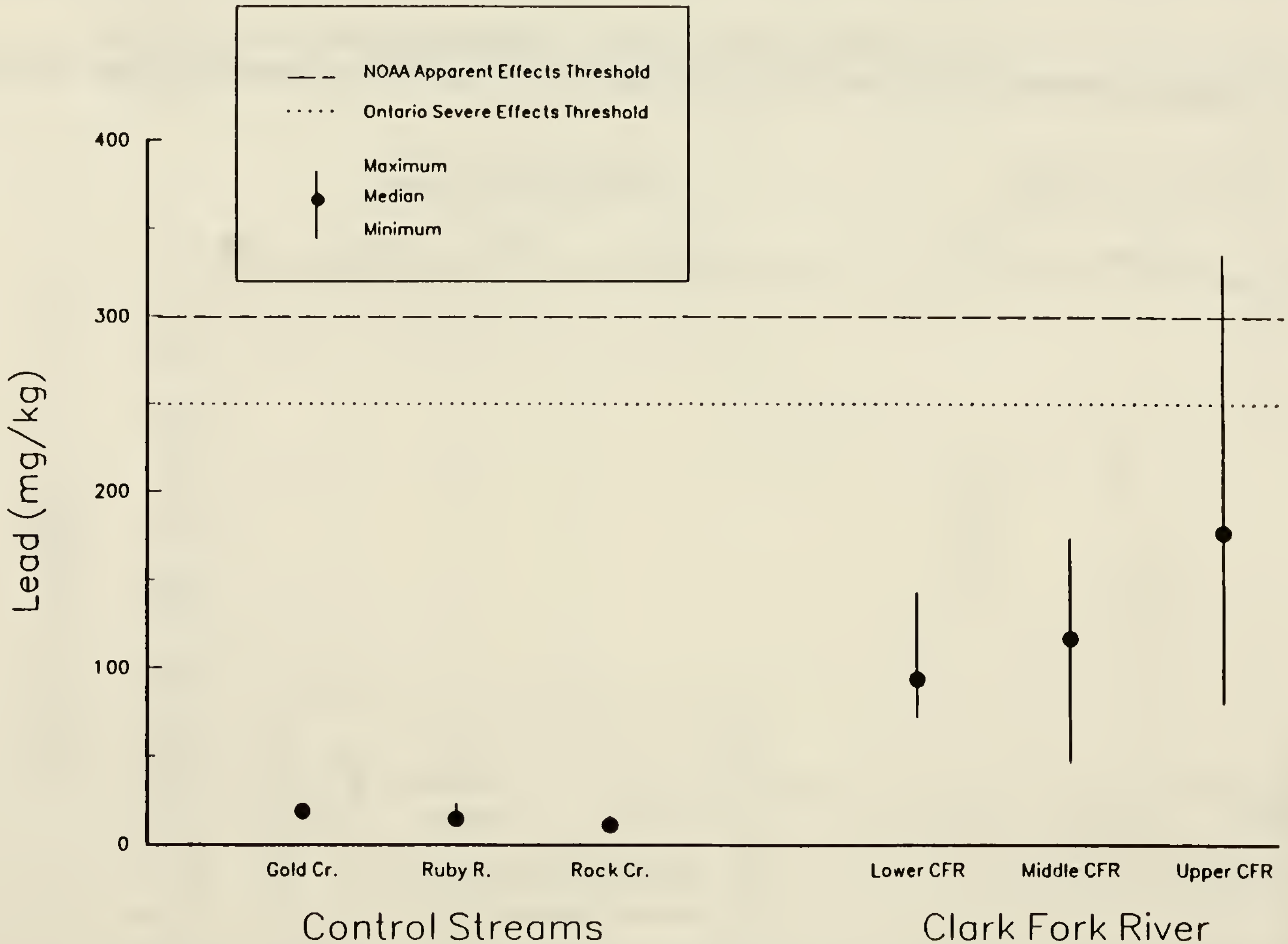

Figure 3-15. Median Concentrations of Lead in Clark Fork River and Control Stream Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

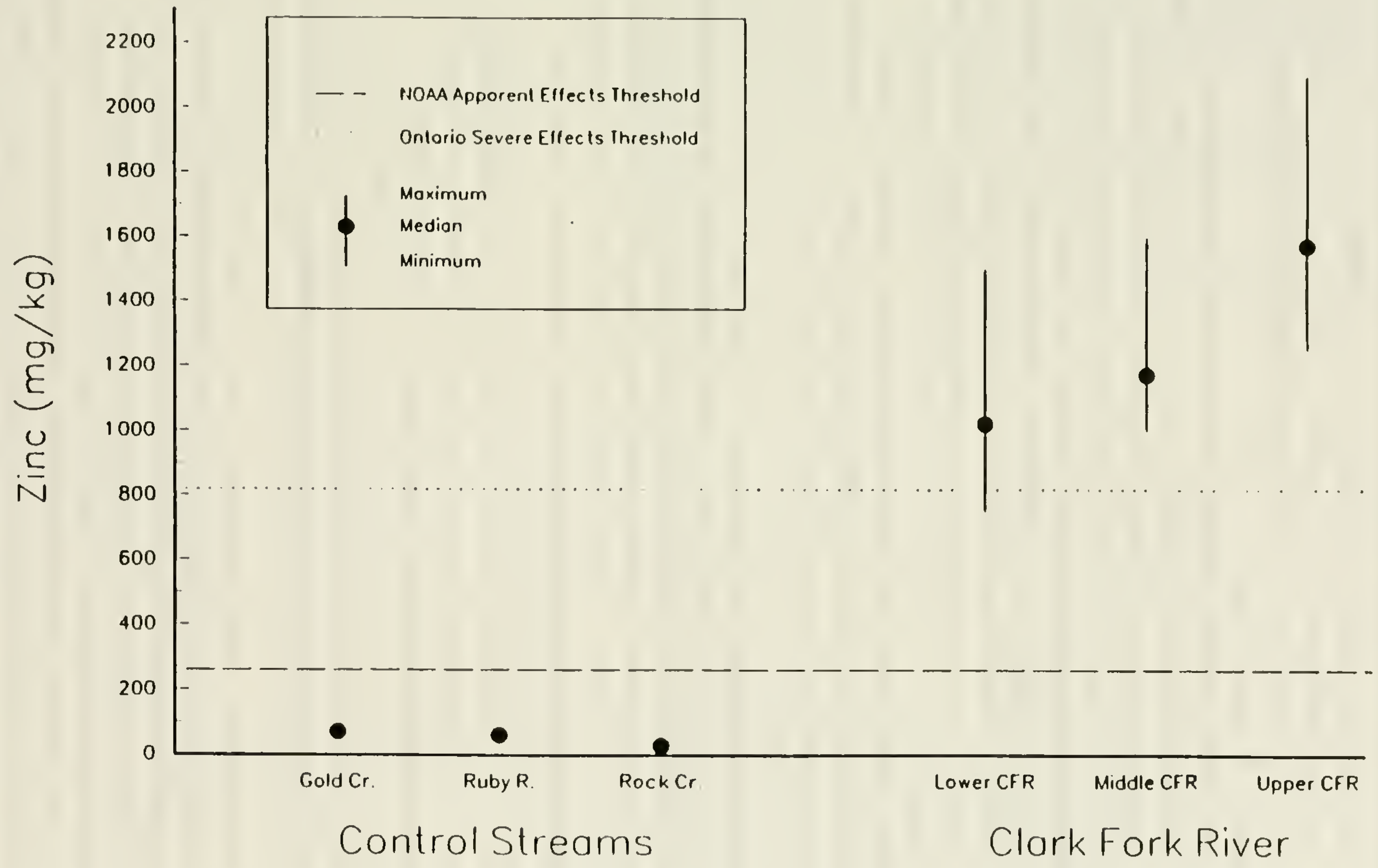

Figure 3-16. Median Concentrations of Zinc in Clark Fork River and Control Stream Bed Sediments Compared with Sediment Threshold Concentrations. Source: Essig and Moore, 1992.

a logarithmic decline in concentrations with downstream distance. Such a pattern is indicative of bed sediment contamination resulting from an upstream source — historic and ongoing releases from Silver Bow Creek, the Warm Springs Ponds, and Warm Springs Creek.

Concentrations of hazardous substances in bed sediments of the Clark Fork River are highest at its origin and generally decrease downstream. Figures 3-2 through 3-6, taken from Essig and Moore (1992), plot arsenic, cadmium, copper, lead, and zinc concentrations in fine bed sediment (< 63 μm) versus river mile. The downstream trend of these hazardous substances follows a log-linear progression at least as far downstream as the Milltown Reservoir, 195 kilometers (120 miles) downstream of the Clark Fork River origin near the Warm Springs Pond. Other investigations have also documented this log-linear relationship in the Clark Fork River between Warm Springs Ponds and Milltown (Axtmann et al., 1990; Axtmann and Luoma, 1991; Moore, 1985). Such a log-linear decline of hazardous substances with river mile is indicative of releases from an upstream source being diluted by cleaner sediment input downstream of the source (Essig and Moore, 1992; Axtmann et al., 1990; Axtmann and Luoma, 1991; Lambing, 1991; Moore, 1985). In the case of the Clark Fork River, the upstream sources consist of the historic and ongoing releases in the Butte and Anaconda areas, as described in Chapter 2.0.

2. **Hazardous substances corresponding to those found in bed sediments of the Clark Fork River are known to have been released in large quantities to the Clark Fork River from mining and mineral processing operations in Butte and Anaconda. No other significant sources of these hazardous substances are known to occur along the Clark Fork River, including sediment input from its tributaries.**

As described in Chapter 2.0, Butte and Anaconda area mining and mineral processing operations have been and continue to be primary sources of the hazardous substances arsenic, cadmium, copper, lead, and zinc to the Clark Fork River via Silver Bow Creek.

Clark Fork River tributaries below Warm Springs Ponds generally have much lower concentrations of arsenic, cadmium, copper, lead, and zinc in sediments than the Clark Fork River (Essig and Moore, 1992; Axtmann and Luoma, 1991; Moore, 1985; Lambing et al., 1994). Although mining activity within the drainage basins of these tributaries has caused elevated metals concentrations in some tributary sediments, neither the mining nor the metals contamination approaches the scale of Butte-Anaconda operations and contamination (Essig and Moore, 1992). Of these tributary drainage basins, the Flint Creek basin has been impacted the most by hard rock mining and mineral processing; Flint Creek sediments are elevated above control stream bed sediments in arsenic, cadmium, lead, and zinc (Essig and Moore, 1992). Nevertheless, detailed studies of bed sediment concentrations near the mouth of Flint Creek show that the effects of metals input from Flint Creek to the Clark Fork River are in a short distance overwhelmed by the contamination of Clark Fork River bed sediments

from Butte and Anaconda area sources (Essig and Moore, 1992; Axtmann and Luoma, 1991). Figures 3-17 through 3-24, taken from Essig and Moore (1992), show the pattern of hazardous substances in bed sediments of the Clark Fork River in the immediate vicinities of the tributaries Little Blackfoot River, Gold Creek, Rock Creek, and Flint Creek. The figures show that inputs from tributary streams have little or no measurable impact on hazardous substance concentrations in the Clark Fork River.

Sediment "fingerprinting" studies, in which the ratios of different bed sediment metals concentrations are compared within and between streams, also demonstrate that hazardous substances in bed sediments of the Clark Fork River originate from sources in Butte and Anaconda and not other tributaries. The ratios of sediment metals within any given stream depend on the types of metals sources within that stream and the geochemical processes which may selectively partition elements. Therefore, similar ratios in sediments from different areas imply similar source chemistry. Conversely, different metals ratios generally imply different source chemistry (Essig and Moore, 1992).

In general, the ratios of arsenic, cadmium, copper, lead, and zinc concentrations in bed sediments are relatively constant throughout the Clark Fork River from its headwaters near Warm Springs to Milltown, and Silver Bow Creek is the only tributary with elemental ratios similar to those of the Clark Fork River (Essig and Moore, 1992). This pattern indicates that bed sediments in Silver Bow Creek and in the entire Clark Fork River downstream to Milltown share the same primary source(s) of these hazardous substances, and that no other tributaries contribute any appreciable amount of these hazardous substances to the bed sediments of the Clark Fork River (Essig and Moore, 1992).

3. Significant downstream transport of hazardous substances has been documented in studies of metal loads in Silver Bow Creek and the Clark Fork River.

Measurements of hazardous substance concentrations in suspended sediment of the Clark Fork River and its tributaries demonstrate that much higher loads of metals are carried downstream by the Clark Fork River compared to its tributaries (ENSR, 1992; Lambing, 1991). Table 3-5 presents data on the average annual loadings of these substances in the Clark Fork River and in two major tributaries.

Large amounts of the hazardous substance-containing material have been transported downstream by the Clark Fork River and deposited along its banks and floodplains (Moore and Luoma, 1990; Nimick, 1990). Floodplain deposits act as continuous secondary sources to Clark Fork River bed sediments through erosion, runoff, and leaching of soluble substances into surface water or groundwater and subsequent deposition to sediments (Nimick, 1990). Thus contaminated floodplain soils are an important ongoing secondary source by which the Clark Fork River is continuously exposed to hazardous substances (ENSR, 1992; Lambing, 1991).

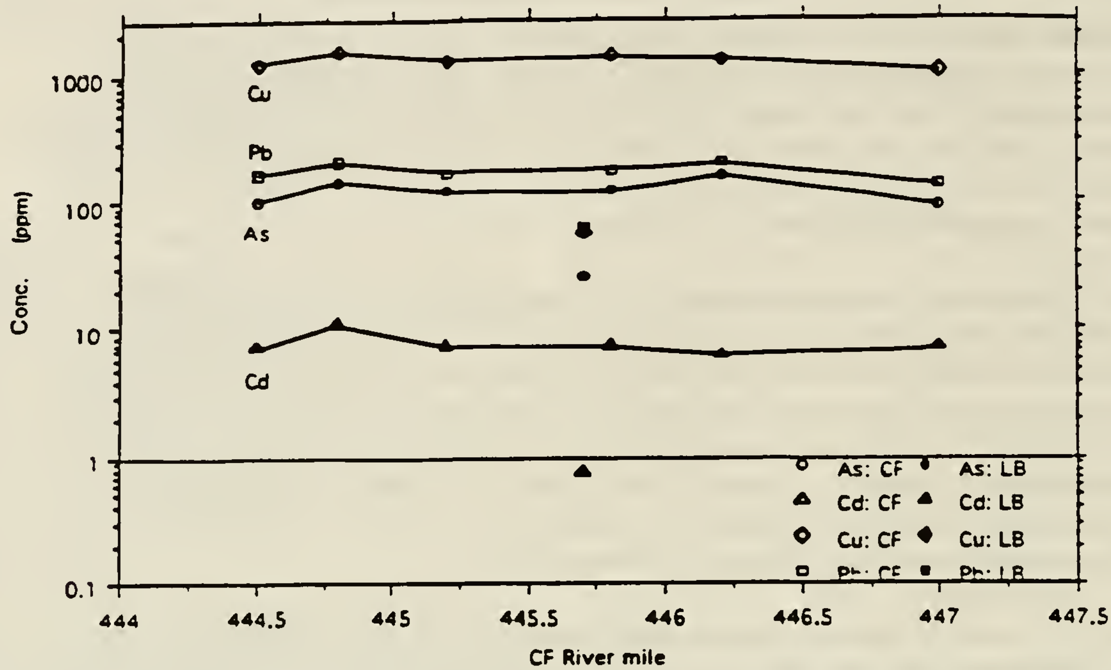

Figure 3-17. Concentrations of Hazardous Substances in Clark Fork River Sediments Near Little Blackfoot River. Source: Essig and Moore, 1992.

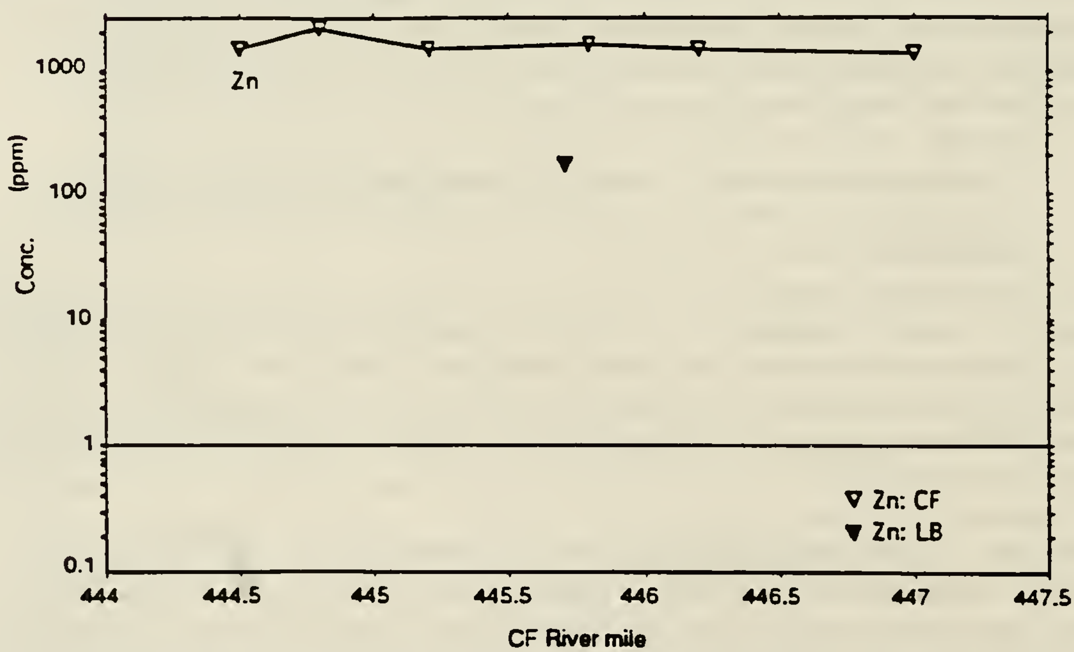

Figure 3-18. Concentrations of Zinc in Clark Fork River Sediments Near Little Blackfoot River. Source: Essig and Moore, 1992.

(CF = Clark Fork River; LB = Little Blackfoot River)

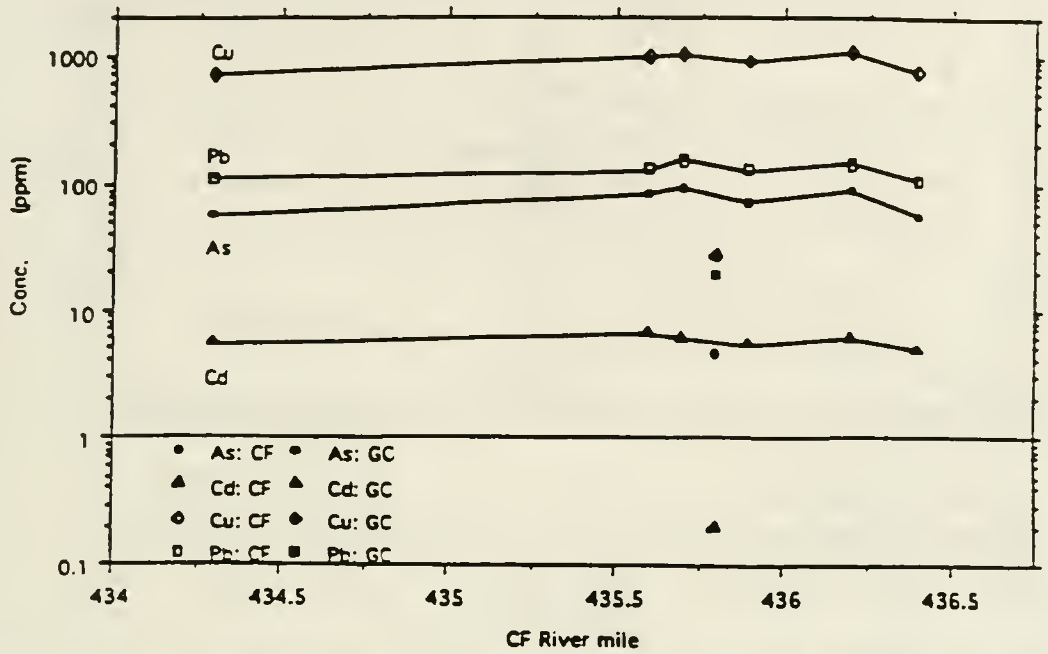

Figure 3-19. Concentrations of Hazardous Substances in Clark Fork River Sediments Near Gold Creek. Source: Essig and Moore, 1992.

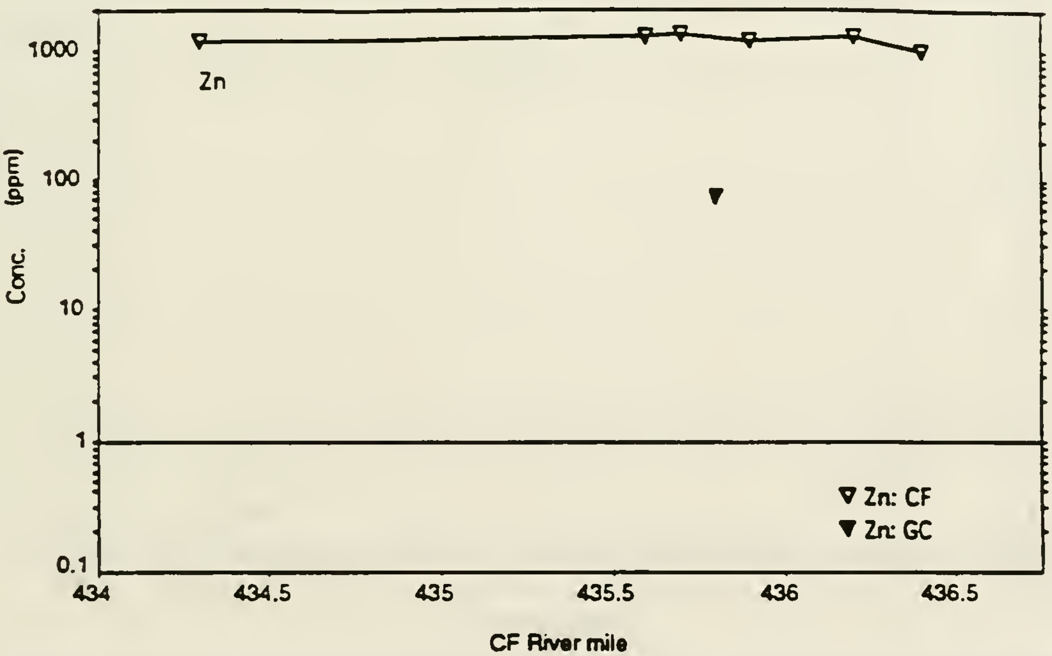

Figure 3-20. Concentrations of Zinc in Clark Fork River Sediments Near Gold Creek. Source: Essig and Moore, 1992.

(CF = Clark Fork River; GC = Gold Creek)

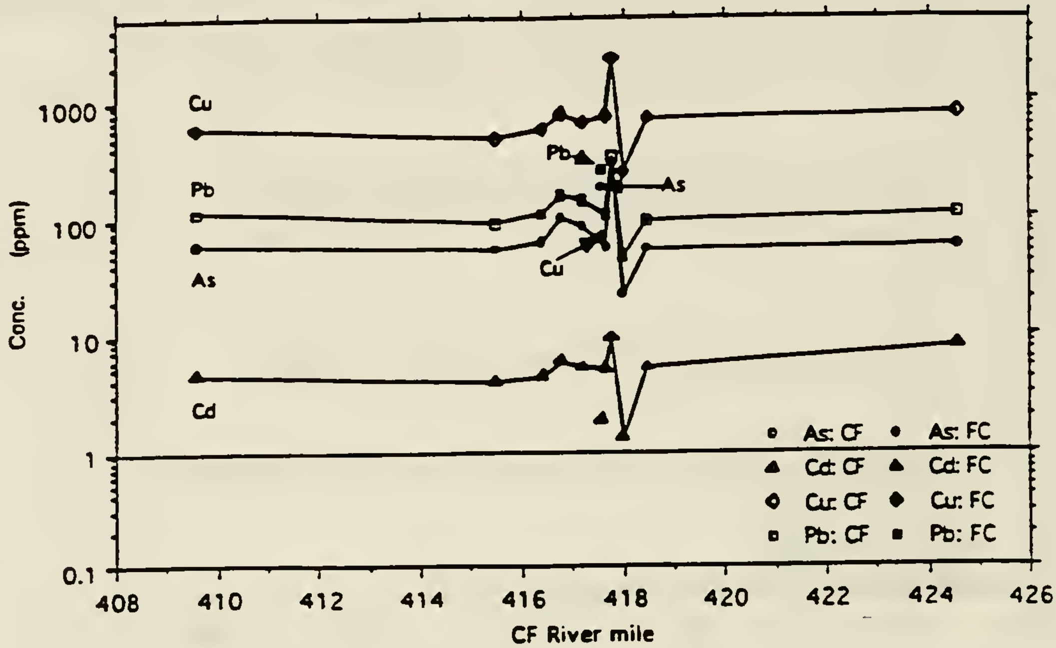

Figure 3-21. **Concentrations of Hazardous Substances in Clark Fork River Sediments Near Flint Creek.** Source: Essig and Moore, 1992.

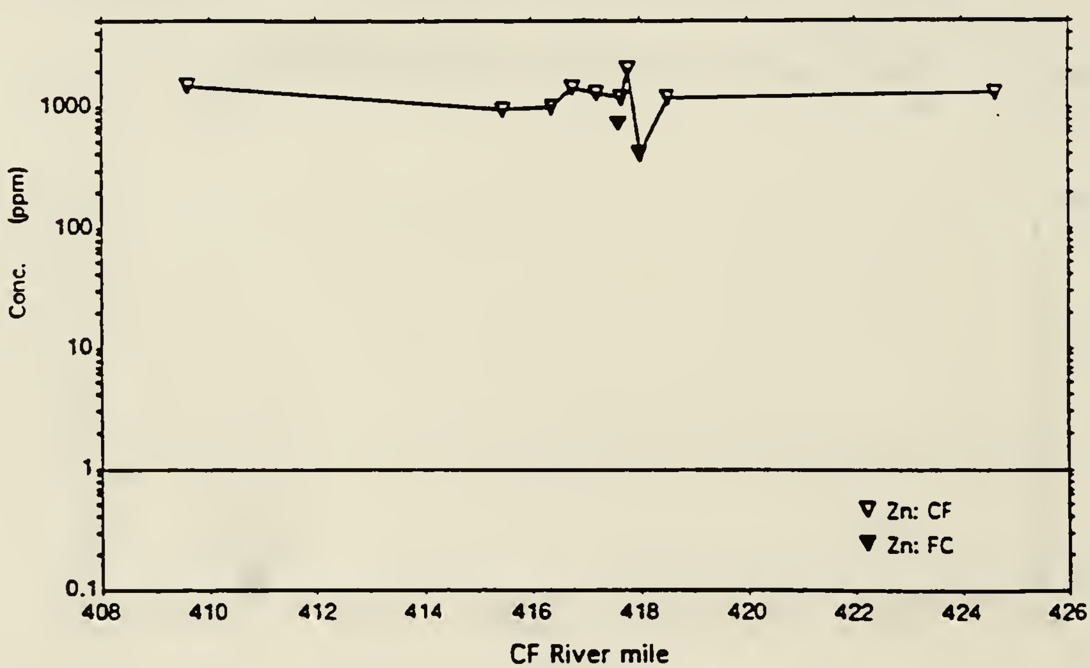

Figure 3-22. **Concentrations of Zinc in Clark Fork River Sediments Near Flint Creek.** Source: Essig and Moore, 1992.

(CF = Clark Fork River; FC = Flint Creek)

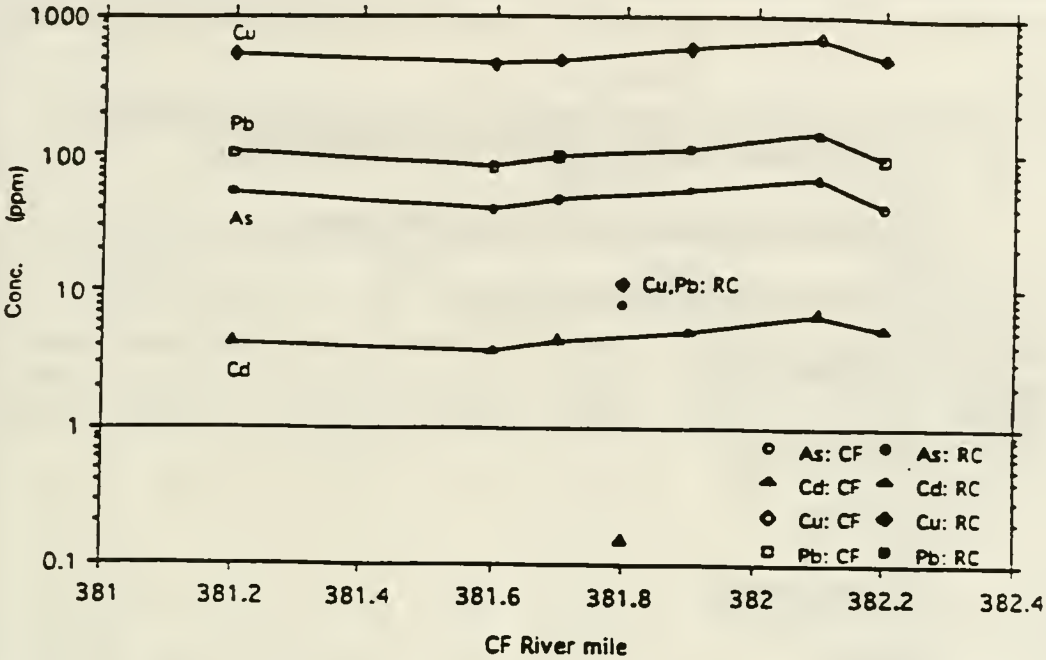

Figure 3-23. **Concentrations of Hazardous Substances in Clark Fork River Sediments Near Rock Creek.** Source: Essig and Moore, 1992.

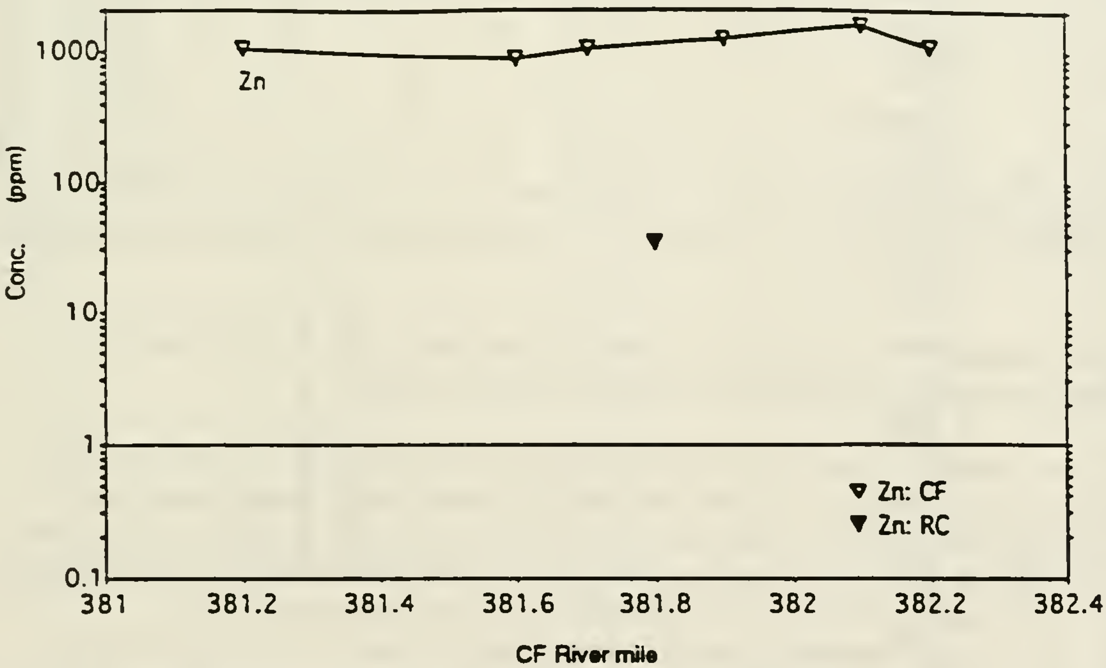

Figure 3-24. **Concentrations of Zinc in Clark Fork River Sediments Near Rock Creek.** Source: Essig and Moore, 1992.

(CF = Clark Fork River; RC = Rock Creek)

Table 3-5
Median Concentrations and Mean Annual Estimated Loads of Hazardous Substances in Suspended Sediment in the Clark Fork River
1986-1990

Clark Fork River Location:	Arsenic		Copper		Lead		Zinc	
	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)	Conc. in Suspended Sediment (mg/kg)	Annual Load (tons)
CFR at Galen	400	1.6	1,950	4.5	250	0.4	3,800	6.2
CFR at Deer Lodge	140	3.3	1,200	11.7	160	1.4	1,700	16.8
CFR at Turah	50	7.1	550	37.2	125	12.3	1,200	44.4
Rock Creek (control)	10	0.2	200	1.5	50	1.3	850	4.1
Little Blackfoot River (control)	25	0.6	120	0.6	35	0.4	300	1.0

Source: Lambing, 1991.

3.5 COMPARISON OF SEDIMENT CONCENTRATIONS OF HAZARDOUS SUBSTANCES AT FISH POPULATION STUDY SITES

Fine-grained bed sediments were collected from 18 test sites in Silver Bow Creek and the Clark Fork River and 18 matched control sites for the fisheries injury quantification (see Section 6.5 for site descriptions). This work was conducted to assess whether concentrations of hazardous substances in bed sediments at Silver Bow Creek and Clark Fork River test sites exceeded concentrations in sediments at control sites that support baseline fisheries populations. One to eight sediment samples were collected at each site. Essig and Moore (1992) present the results of this sediment sampling and compare sediment hazardous substance concentrations between test and control sites. Mean sediment concentrations were calculated if more than one sediment sample was collected at a fish population site. Differences between the paired test and control sites were assessed statistically. The results (Figures 3-25 through 3-29) show a highly significant ($p < 0.01$) elevation in sediment

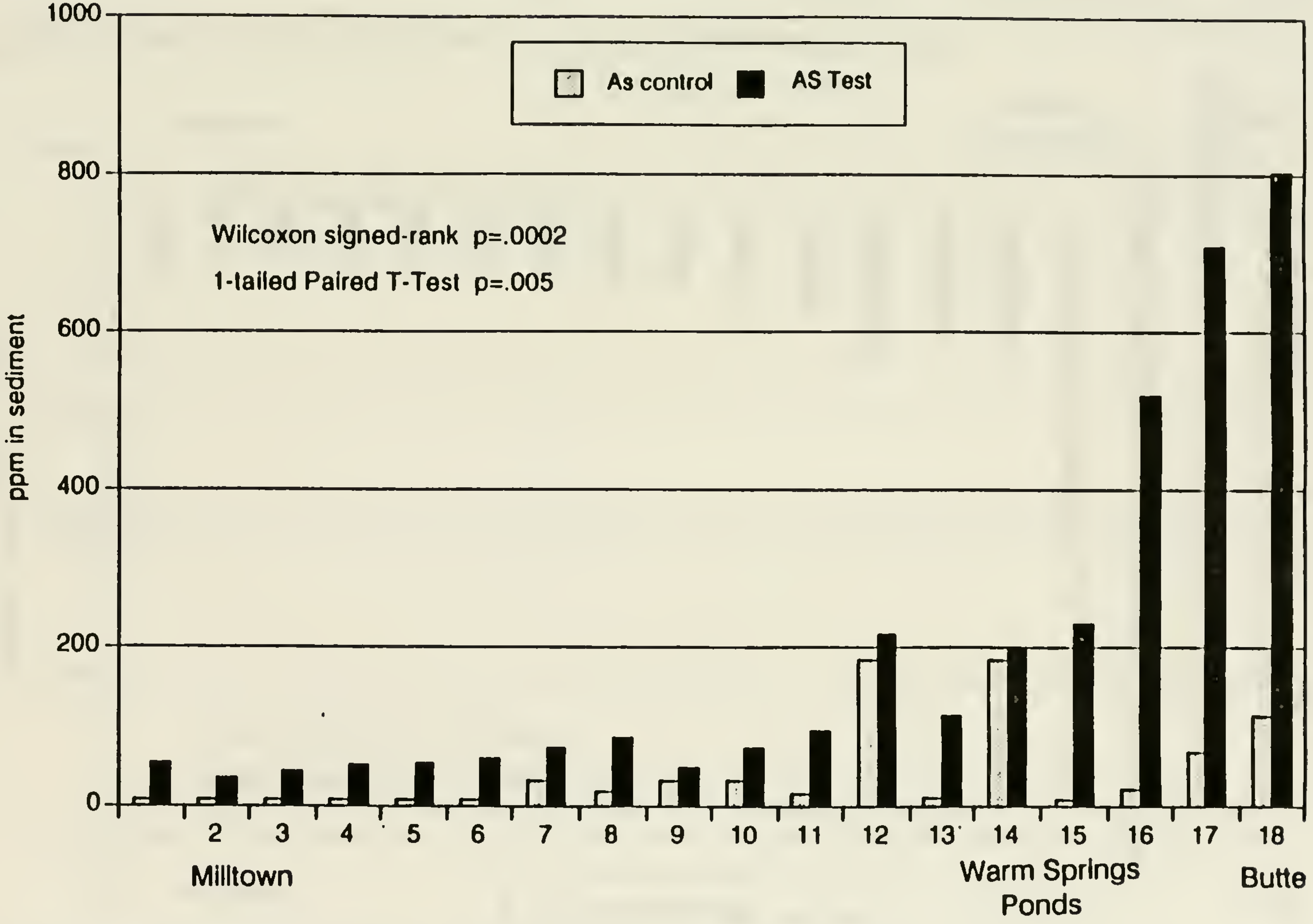

Figure 3-25. Sediment Arsenic by Stream Pairs. Source: Essig and Moore, 1992.

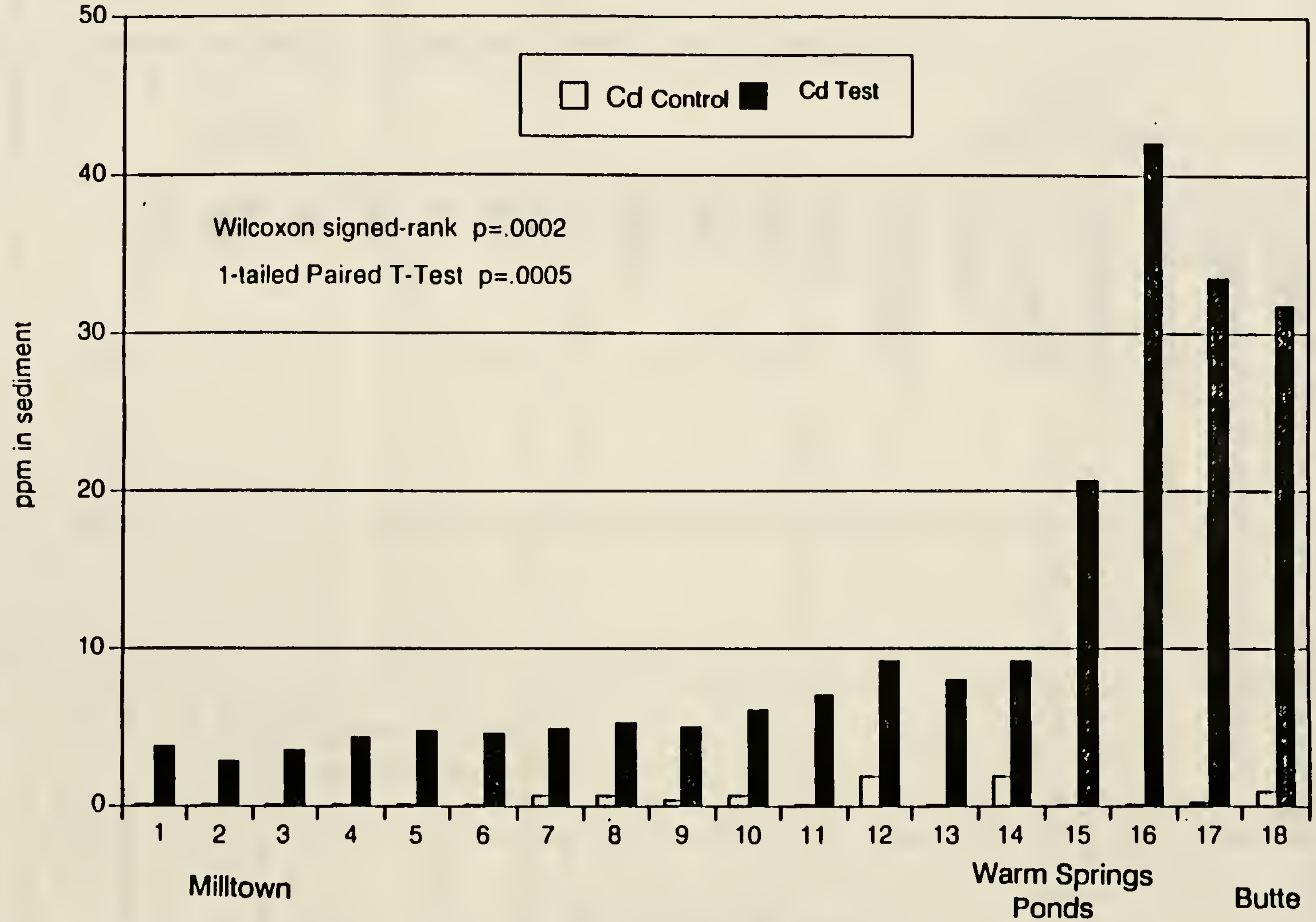

Figure 3-26. Sediment Cadmium by Stream Pairs. Source: Essig and Moore, 1992.

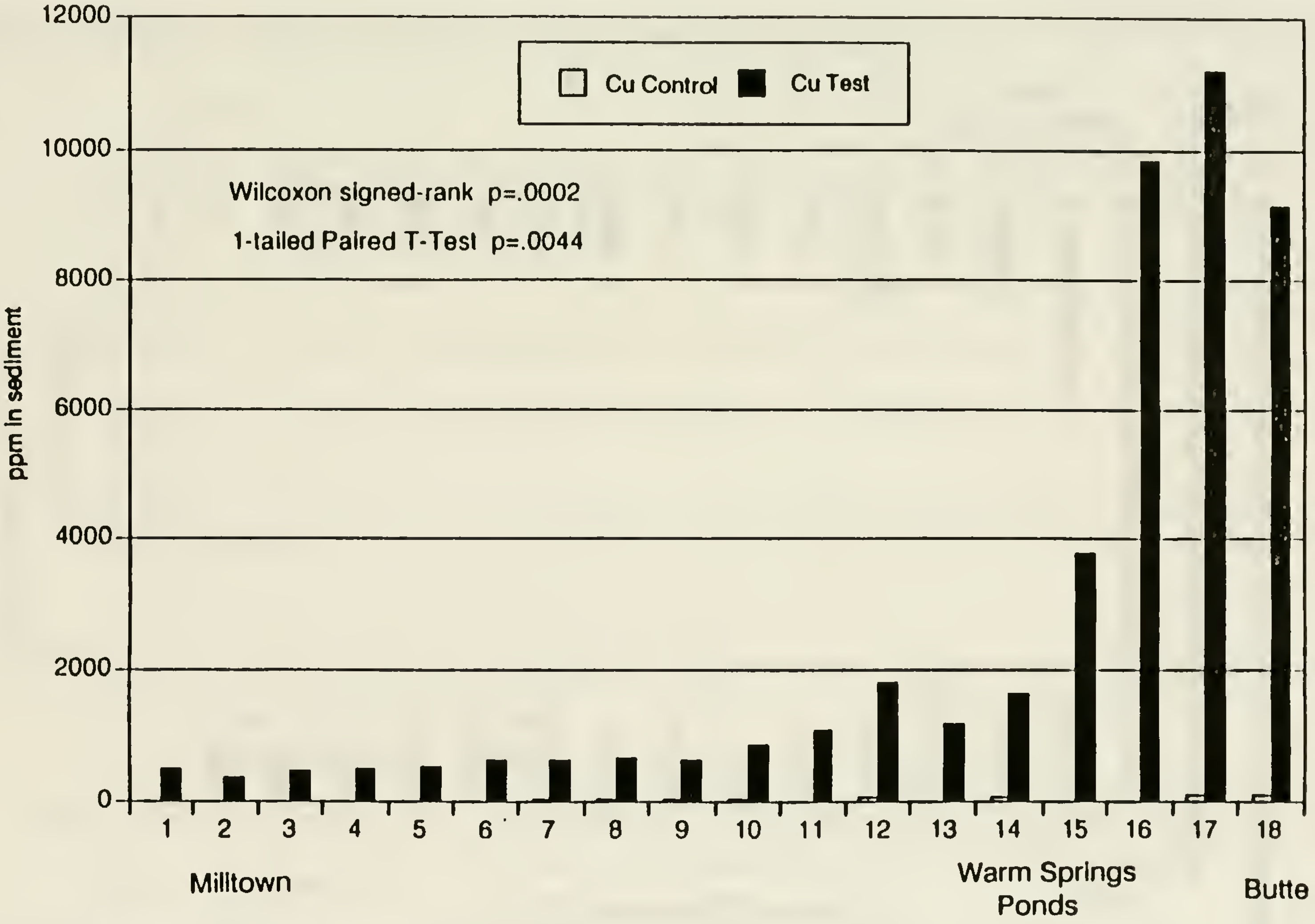

Figure 3-27. Sediment Copper by Stream Pairs. Source: Essig and Moore, 1992.

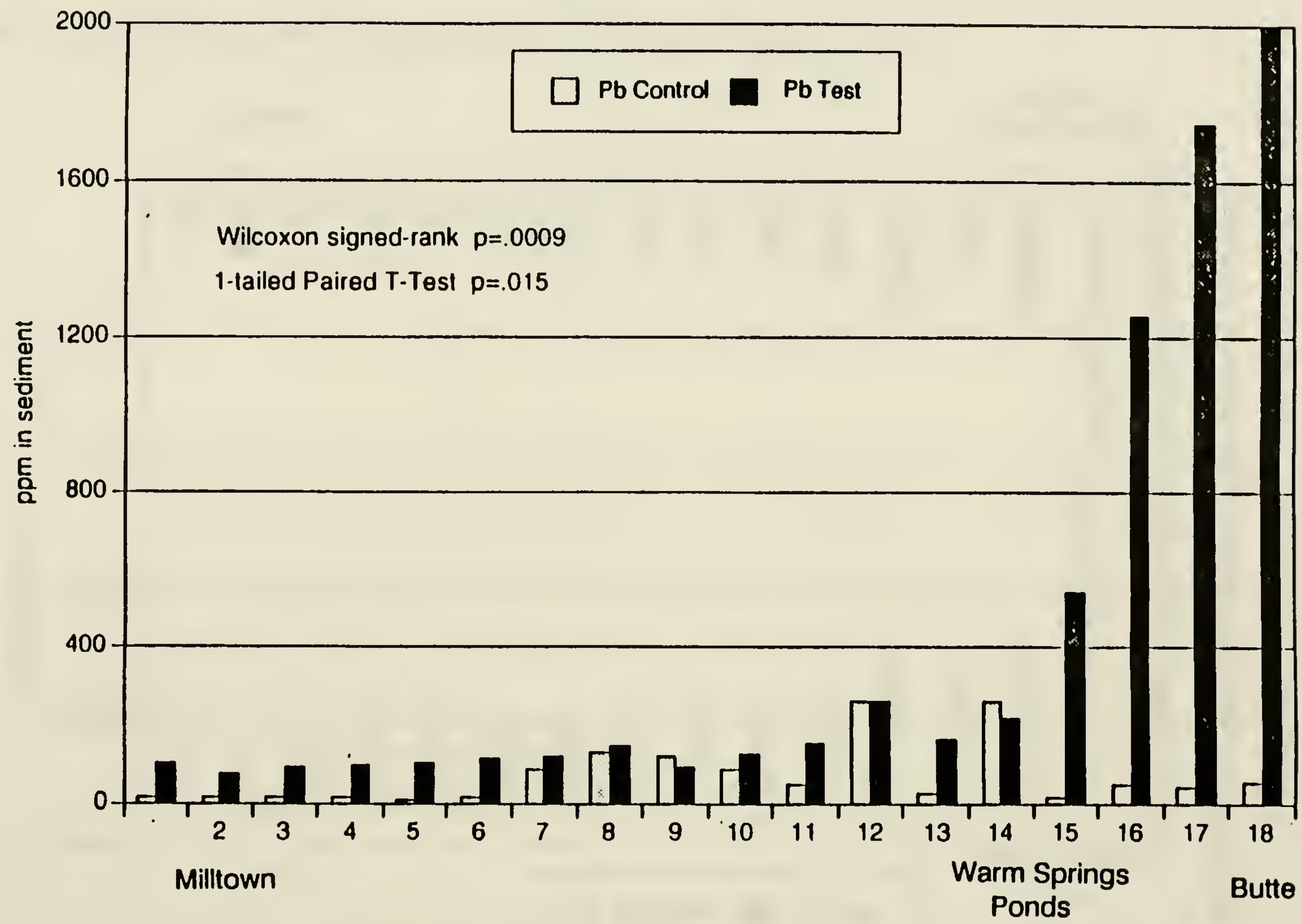

Figure 3-28. Sediment Lead by Stream Pairs. Source: Essig and Moore, 1992.

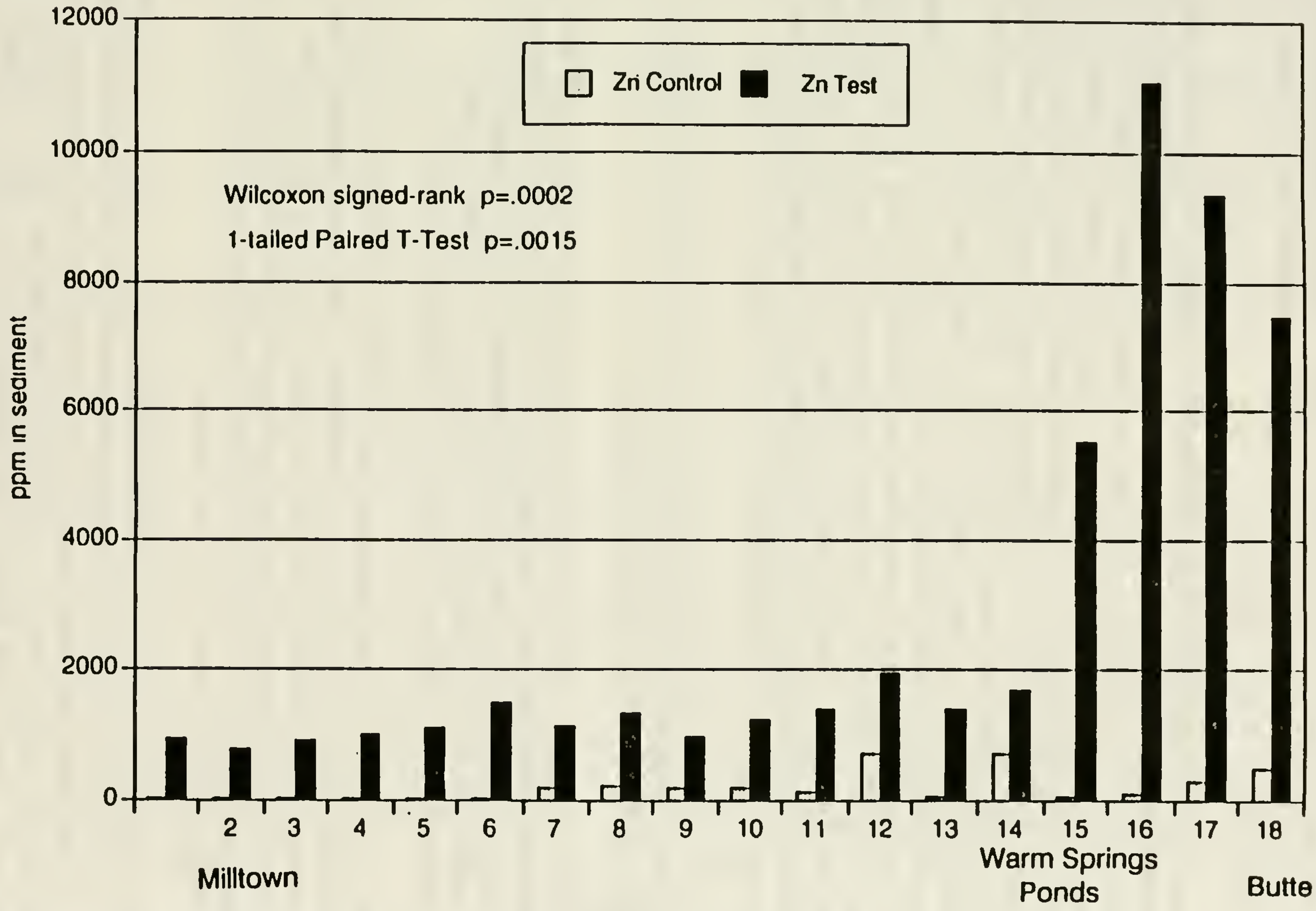

Figure 3-29. Sediment Zinc by Stream Pairs. Source: Essig and Moore, 1992.

hazardous substance concentrations in the Clark Fork River and Silver Bow Creek sediments relative to their matched controls. Concentrations of arsenic, cadmium, copper, and zinc were higher at all 18 test sites than at the matching controls. Lead concentrations were higher at 17 of the 18 controls.

Test and control stream sediments were also compared by calculating the ratio of the mean metals concentrations in the test stream to the mean concentrations in the control streams for each of the 18 pairs. Where concentrations in test and control streams are equal, ratios equal one. Ratios greater than one indicate the magnitude by which test stream concentrations exceed control stream concentrations. Ratios were calculated for arsenic, cadmium, copper, lead, and zinc for the 18 site pairs, and are presented as mean sediment metal elevation in test streams (Figure 3-30). The mean concentrations of both copper and cadmium in test sites exceeded mean concentrations in control sites by a factor of more than 70. Zinc concentrations at test sites exceeded concentrations at control sites by a factor of more than 25. Lead and arsenic concentrations at test sites exceeded those at control sites by factors of approximately 10 and 7, respectively. The overall conclusion to be drawn from this analysis is consistent with the other sediment analyses: bed sediments of Silver Bow Creek and the Clark Fork River are contaminated with hazardous substances at concentrations that greatly exceed concentrations at sites that support baseline fish populations (see Chapter 6.0).

3.6 PATHWAYS OF HAZARDOUS SUBSTANCES TO SILVER BOW CREEK AND CLARK FORK RIVER BED SEDIMENTS

The bed sediments of Silver Bow Creek and the Clark Fork River are highly contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc. These hazardous substances originated from releases from mining and mineral processing operations in the Butte and Anaconda areas. The pathways by which sediments have been exposed to hazardous substances are surface water/sediment and groundwater pathways.

As described in Chapter 2.0, Silver Bow Creek received direct discharge of raw mining and mineral processing wastes containing hazardous substances. These direct discharges have been, and continue to be transported downstream in dissolved form and as suspended particulate matter (see Chapter 4.0). Thus, both surface water and sediments act as pathways to downstream exposed areas (Andrews, 1987; Axtmann and Luoma, 1991; ENSR, 1992; Lambing, 1991; Moore and Luoma, 1990; Lambing et al., 1994).

In addition to surface water/sediment pathways, groundwater acts as a pathway to exposed sediments. As described in Chapter 2.0, groundwater contaminated with hazardous substances discharges to Silver Bow Creek near Lower Area One. Shallow alluvial groundwater underlying streamside tailings, such as in the Miles Crossing area, also acts as a pathway to Silver Bow Creek. Some of these dissolved metals precipitate out of solution or adsorb to particulates as Silver Bow Creek gradually becomes less acidic as it moves downstream (Canonie, 1992).

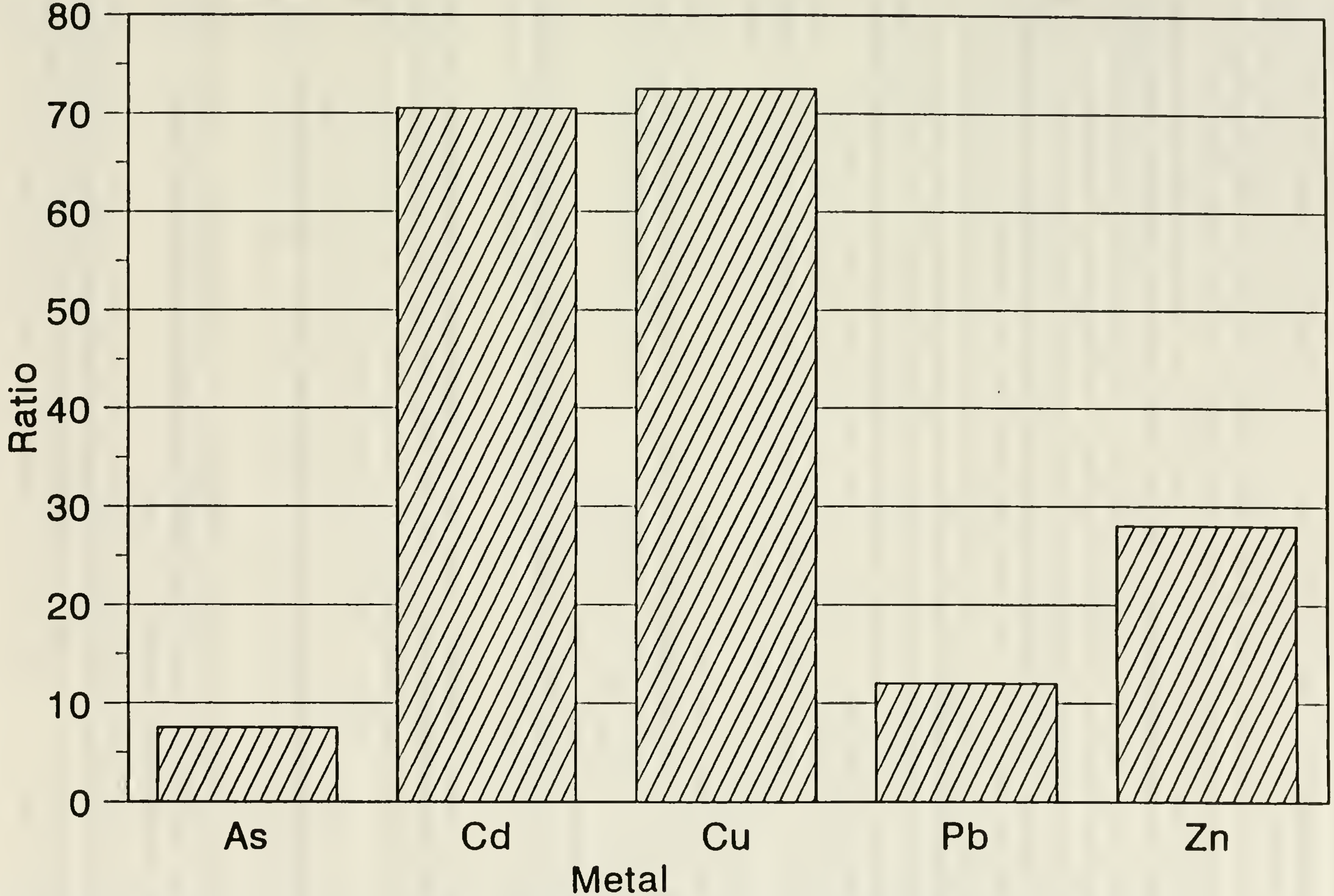

Figure 3-30. Mean Ratio of Test vs. Control Sediment Metals Concentrations. Source: Essig and Moore, 1992.

3.7 SUMMARY

The sediments of Silver Bow Creek, Warm Springs Ponds, and the Clark Fork River are highly contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc and are an exposure pathway to surface water, downstream sediments, and aquatic biota. This contamination is a result of large-scale mining and mineral processing operations in the Butte and Anaconda areas. No other significant sources of these hazardous substances are known to occur along Silver Bow Creek, the Clark Fork River, or their tributaries. Furthermore, the downstream decline of hazardous substance concentrations within the Clark Fork River and sediment "fingerprinting" studies also demonstrate that hazardous substances in sediments of Silver Bow Creek and the Clark Fork River originated from the Butte and Anaconda areas. Significant downstream transport of hazardous substances has been documented in studies of Silver Bow Creek and the Clark Fork River. These studies support the conclusion that upstream sources are responsible for downstream contamination. Finally, a dramatic and highly significant elevation in sediment hazardous substance concentrations occurs at the fish population sampling locations in Silver Bow Creek and the Clark Fork River relative to locations in control streams.

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4.0 SURFACE WATER

4.1 INTRODUCTION

This chapter presents the determination and quantification of injury to surface water resources of Silver Bow Creek and the Clark Fork River. In addition to the injury caused by hazardous substances, surface water serves as an important pathway of metals to fish, and interacts closely, if not inseparably, with bed sediments in the migration of metals from upstream source areas to downstream reaches. The surface water chapter is organized as follows: Section 4.2 presents the results of injury determination; Section 4.3 quantifies those injuries and discusses the recoverability of the resource; Section 4.4 compares metals concentrations at fish population study sites in the injured resource to control fish study sites; and Section 4.5 discusses the pathways by which hazardous substances have migrated or have been transported from source areas to the surface waters of Silver Bow Creek and the Clark Fork River.

4.2 INJURY DETERMINATION

4.2.1 Injury Definition

Surface water resources of Silver Bow Creek and the Clark Fork River have been injured according to the following definitions:

- Concentrations and duration of substances in excess of applicable water quality criteria established by section 304(a)(1) of the CWA (Clean Water Act), or by other Federal or State laws or regulations that establish such criteria, in surface water that before the discharge or release met the criteria and is a committed use...as a habitat for aquatic life, water supply, or recreation [43 CFR § 11.62 (b)(iii)].

- Concentrations and duration of substances sufficient to have caused injury...to biological resources when exposed to surface water, suspended sediments, or bed, bank, or shoreline sediments [43 CFR § 11.62 (b)(v)].

The DOI NRDA regulations provide that there is an injury to surface water if the concentrations and duration of substances are in excess of applicable water quality criteria in surface water that before the release met the criteria, and the surface water resource has a "committed use" as a habitat for aquatic life, water supply or recreation. A "committed use" is defined as either a current public use or a planned public use for which there is a documented legal, administrative, budgetary, or financial commitment before the release of a hazardous substance is detected [43 CFR § 11.14(h)]. In spite of the injuries resulting from releases of hazardous substances, the Clark Fork River still has current public uses as a

habitat for aquatic life (e.g., fish and benthic macroinvertebrates), water supply (e.g., irrigation), and recreation (e.g., fishing). The public use of Silver Bow Creek has been severely impacted by the release of hazardous substances. Nevertheless, Silver Bow Creek also has current public uses as a habitat for aquatic life (e.g., benthic macroinvertebrates), water supply (e.g., irrigation), and is used for recreational purposes as reported in RI/FS documents (CDM, 1992 as cited in Montgomery Consulting, 1992). These past, present and future uses of the Clark Fork River and Silver Bow Creek have been documented by various statutory, regulatory, administrative, budgetary, and/or financial commitments by the State. This includes the establishment of applicable surface water quality standards by the Montana Department of Health and Environmental Sciences (MDHES) (MDHES, 1994).

The first injury definition, exceedences of water quality criteria, is evaluated and discussed in this chapter. The second injury definition, injury to biological resources, is evaluated and discussed in Chapter 5.0 (benthic macroinvertebrates by exposure to bed sediments) and Chapter 6.0 (fish by exposure to surface water).

4.2.2 Category of Injury: Exceedences of Ambient Water Quality Criteria

4.2.2.1 Criteria Definitions

Pursuant to Section 304(a)(1) of the Clean Water Act [33 U.S.C. 1314 (a)(1)], the U.S. Environmental Protection Agency (U.S. EPA) established ambient water quality criteria (AWQC) for the protection of aquatic life. AWQC have been established for over 100 substances, including cadmium, copper, lead, and zinc. These numeric criteria have been adopted by the State of Montana as surface water quality standards. AWQC for these substances are expressed in terms of *acute* (one-hour average) and *chronic* (four-day average) criteria, which are not to be exceeded more than once every three years. Criteria for cadmium, copper, lead and zinc are hardness-dependent (i.e., vary as the hardness of the water changes). Criteria for hard waters are higher than criteria for soft waters because metals tend to be more toxic at lower hardnesses. Criteria equations are presented in Table 4-1.

U.S. EPA's guidance for interpreting and implementing aquatic life metals criteria (Prothro, 1993) notes that the dissolved concentration of a metal *may* better approximate the bioavailable fraction in aqueous exposures than the total recoverable concentration. Although U.S. EPA recommends using the dissolved metal to set and measure compliance with water quality standards, it notes that particulate (i.e., total recoverable) metals can contribute to the overall toxicity to aquatic ecosystems in locations where the water column is not the only route of exposure. For example, in the Clark Fork River contaminated bed sediments have been shown to contaminate benthic macroinvertebrates (see Chapter 5.0), which are consumed by fish and result in mortality and decreased growth (see Chapter 6.0). The State of Montana adopted a total recoverable method for evaluating compliance with ambient water quality

Table 4-1
Hardness-Dependent Ambient Water Quality Criteria (AWQC)[1]
(criteria calculated in µg/l)

Metal	Acute AWQC	Chronic AWQC
	Equation	Equation
Cadmium	$e^{(1.128\{\ln(\text{hardness})\}-3.828)}$	$e^{(0.7852\{\ln(\text{hardness})\}-3.490}$
Copper	$e^{(0.9422\{\ln(\text{hardness})\}-1.464)}$	$e^{(0.8545\{\ln(\text{hardness})\}-1.465)}$
Lead	$e^{(1.273\{\ln(\text{hardness})\}-1.460)}$	$e^{(1.273\{\ln(\text{hardness})\}-4.705)}$
Zinc	$e^{(0.8473\{\ln(\text{hardness})\}+0.8604)}$	$e^{(0.8473\{\ln(\text{hardness})\}+0.7614)}$

[1] U.S. EPA, 1986; MDHES, 1994.

criteria (MDHES, 1994). This is consistent with U.S. EPA guidance which states that "a risk manager may consider sediment and food-chain effects and may decide to take a conservative approach for metals, considering that metals are very persistent chemicals" (Prothro, 1993). Therefore, this assessment compares total recoverable concentrations to ambient water quality criteria for the purpose of determining injury to surface water.

U.S. EPA defines exceedences of AWQC in terms of one-hour (acute) and four-day (chronic) *average* concentrations that are not to be exceeded more frequently than once during a three-year period, on average. (U.S. EPA believes that three years is the period of time that disturbed aquatic communities need to recover from impacts related to toxic substances.) The State of Montana has defined slightly different time frames for determining compliance with AWQC. For acute criteria, no sample shall exceed the relevant numeric criterion for any time period. For chronic criteria, no concentration based on a 4-day, *or longer*, averaging period may exceed the relevant criterion (MDHES, 1994). Because exceedence "frequency" has not been defined in the State's water quality standards, the frequency defined by U.S. EPA's guidance (three years) has been adopted in this assessment for evaluating injury to surface water.

Based on the above, injury to surface water is determined by:

- A minimum of two exceedences of acute ambient water quality criteria in a three-year period

- A minimum of two exceedences of chronic ambient water quality criteria, based on a 4-day, or longer, averaging period in a three year period.

The acceptance criterion for injury to the surface water resource is measurement of concentrations of a hazardous substance in two samples from the resource [43 CFR § 11.62 (b)(2)(i)]. Samples must be one of the following types:

- Two water samples from different locations not less than 100 feet apart
- Two water samples from the same location collected at different times.

Data used in the injury determination meet these acceptance criteria. Samples have been collected from numerous locations in the 23 miles (37 km) of Silver Bow Creek and the 120 miles (190 km) of the Clark Fork River over a period of many years.

4.2.2.2 Water Quality Data Analysis

The primary source of surface water data was U.S. EPA's national water quality database STORET (Storage Retrieval). Data in STORET are provided by local, state, and federal agencies. Much of the data for the Clark Fork River basin originate from monitoring programs of the MDHES and the U.S. Geological Survey (USGS).

STORET data were retrieved for Silver Bow Creek, the Clark Fork River, and tributary streams. Silver Bow Creek and the Clark Fork River were divided into assessment reaches. Two long reaches which encompassed a large number of sampling sites were divided into smaller assessment units based on clusters of sampling sites. These reaches were the upper Clark Fork River between Warm Springs Ponds and the Little Blackfoot River (CFR6A-6E) and upper Silver Bow Creek between Butte and Durant Canyon below Miles Crossing (SBC9A-9C). Figure 4-1 and Table 4-2 summarize reach descriptions, station location information, and other pertinent information.

Acute and chronic criteria were calculated for cadmium, copper, lead, and zinc for samples which included a hardness concentration (or calcium and magnesium concentrations from which a hardness concentration could be calculated).[1] A water quality criterion exceedence "severity index" was calculated by dividing the concentration of a metal by its acute or chronic criterion. This index is the factor by which a criterion is exceeded. Values greater than one represent criteria exceedences. For evaluating exceedences of acute criteria, all data were used regardless of the duration of the sample collection period. Most samples are collected as instantaneous grab samples; these samples are appropriate for evaluating injury based on the State of Montana's water quality standards (which state that "no sample" shall

[1] Where measured or calculated hardness was greater than 400 mg/l (as $CaCo_3$), a value of 400 mg/l was used to calculate AWQC, in accordance with State of Montana Water Quality Standards (MDHES, 1994).

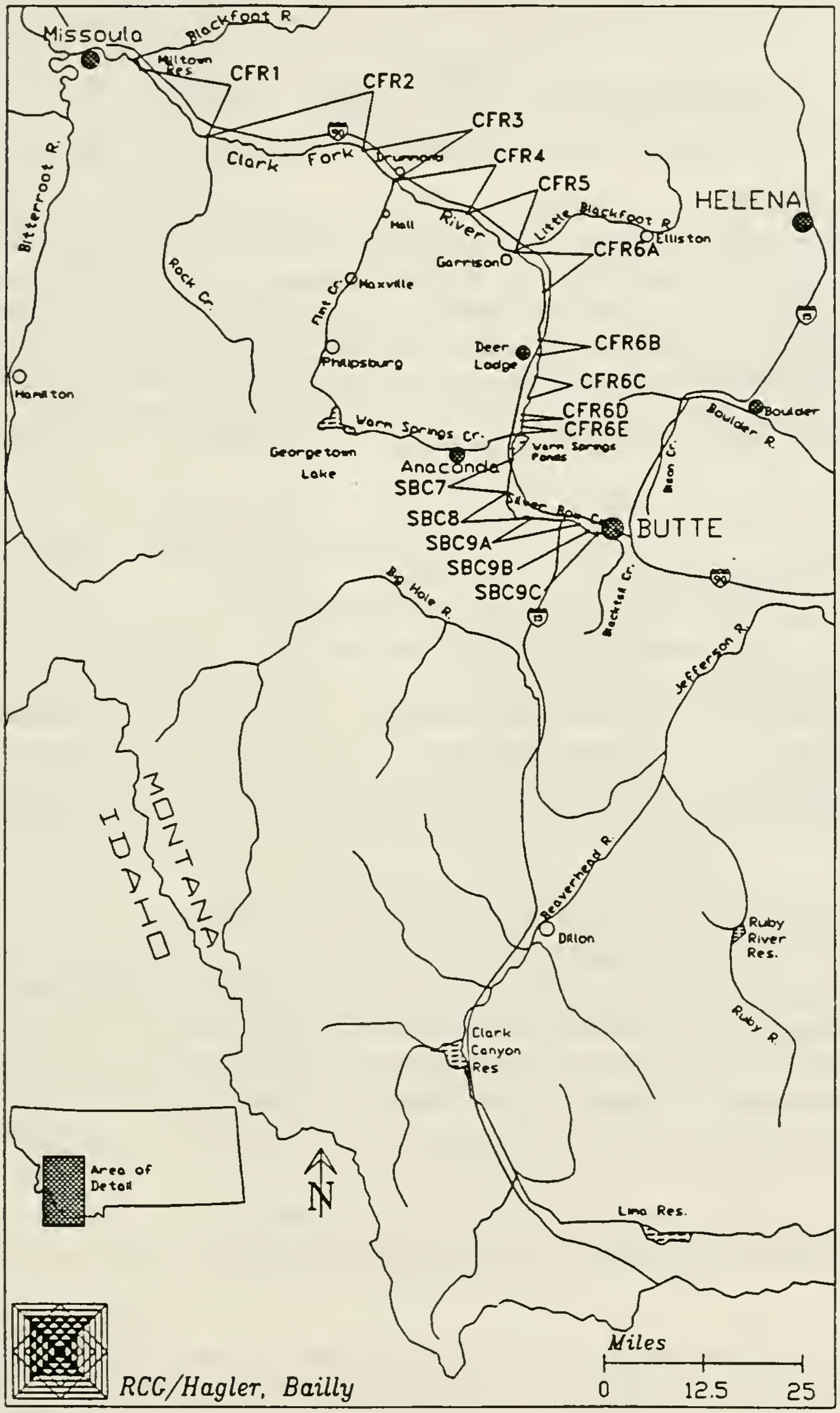

Figure 4-1. Surface Water Reach Locations, Silver Bow Creek and Clark Fork River.

Table 4-2
Reach Descriptions and Station Location Information*

Reach Description	Station Locations	Data Collection Agencies	Period of Record
CFR1 - Milltown Reservoir to Rock Creek	Below Rock Creek, Turah	MDHES, USGS	1977 - 1994
CFR2 - Rock Creek to near Drummond	Bearmouth, Bonita	MDHES, U.S. EPA	1970 - 1991
CFR3 - near Drummond to Flint Creek	Drummond	MDHES, USGS, U.S. EPA	1970 - 1994
CFR4 - Flint Creek to Gold Creek	Gold Creek Bridge, Jens	MDHES	1973 - 1994
CFR5 - Gold Creek to Little Blackfoot River	Near Garrison, Phosphate	MDHES, USGS, U.S. EPA	1968 - 1987
CFR6A - above Little Blackfoot River	Tavenner Ranch Bridge, Kohrs, near Beck Hill, above Little Blackfoot R.	MDHES, U.S. EPA	1970 - 1991
CFR6B - near Deer Lodge	Deer Lodge vicinity	MDHES, USGS	1968 - 1994
CFR6C - near Dempsey	Near Dempsey, Racetrack Bridge, Sager Lane	MDHES, U.S. EPA	1970 - 1991
CFR6D - near Galen	Galen vicinity	MDHES, USGS	1971 - 1994
CFR6E - below Warm Springs Ponds	Below Warm Springs Ponds	MDHES	1978 - 1991
SBC7 - Warm Springs Ponds to canyon bottom near Fairmont	Opportunity, Stewart Street Bridge, Fairmont Road, I-90 Frontage Road	MDHES, U.S. EPA	1970 - 1994
SBC8 - bottom to top of canyon	Below German Gulch	MDHES	1978
SBC9A - top of canyon to Ramsay Flats area	Ramsay, Silver Bow, Rocker, Nissler, Miles Crossing	MDHES, U.S. EPA	1970 - 1991
SBC9B - below Colorado Tailings	Below Colorado Tailings	MDHES	1976 - 1991
SBC9C - above Butte WWTP discharge	Above Butte WWTP	MDHES	1988 - 1994

* Abbreviations: CFR (Clark Fork River); SBC (Silver Bow Creek).

exceed relevant acute criteria). For evaluating exceedences of chronic criteria, samples collected during the spring runoff months of March, April, and May were used. Ambient conditions during these months are usually characterized by the highest concentrations of hazardous substances of any period of the year, due to streambed and streambank scouring associated with ice breakup and the onset of spring runoff. These three months provide an approximately 90-day averaging period, consistent with State of Montana water quality standards.

When evaluating surface water data, it should be noted that sample digestion methods can affect the concentration of metal measured in a sample. The USGS, the U.S. EPA, and the State of Montana each employs a somewhat different digestion method. The Montana method likely recovers a smaller fraction of sediment-bound metals than the U.S. EPA or USGS methods.[1] Therefore, the use of Montana total recoverable data to evaluate injury is conservative. (Data obtained from STORET are derived primarily from studies conducted by the USGS and the State of Montana).[2]

4.2.2.3 Injury to Silver Bow Creek

Data collected from Silver Bow Creek from 1970 to the present time demonstrate injury to surface water by exceedences of both acute and chronic ambient water quality criteria.

The first comprehensive survey of water quality in Silver Bow Creek and the Clark Fork River was conducted by U.S. EPA in 1970 and 1971 (U.S. EPA, 1972). Data were collected from Silver Bow Creek at Ramsay and above Warm Springs Ponds. As illustrated in Table 4-3, surface water exhibited gross contamination by cadmium, copper, and zinc. Several hundredfold exceedences of acute copper criteria were common.

Table 4-4 summarizes acute criteria exceedences since 1985, the earliest year of continuous data collection by MDHES for the long-term Clark Fork River Basin Survey. These data demonstrate that hazardous substances in Silver Bow Creek have exceeded, and continue to exceed, AWQC. For example, 100% of samples collected in Silver Bow Creek (n = 380) exceeded acute copper criteria. All but one sample (n = 376) exceeded acute zinc criteria. Copper criteria were exceeded by a factor as great as 84; zinc criteria were exceeded by a factor as great as 42. Cadmium exceeded acute criteria in a small percentage of samples.

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[2] The Montana total recoverable method was found to measure significantly lower concentrations ($p < 0.05$) of Cd, Cu, Pb and Zn than the U.S. EPA method. A comparison of split samples analyzed following the USGS and Montana methods determined that both methods obtain similar results (See Appendix A).

Table 4-3
Concentration Ranges of Hazardous Substances and Magnitudes of Acute AWQC Exceedences in Silver Bow Creek, 1970-1971 (total metals concentrations in μg/l)[1,2]

Location	Cadmium		Copper		Lead		Zinc	
	Range	Magnitude	Range	Magnitude	Range	Magnitude	Range	Magnitude
Ramsay	1,300 - 3,000	69 - 160	20,000 - 49,000	310 - 750	180 - 970	< 1 - 2	34,000 -120,000	90 - 320
Silver Bow Creek above Warm Springs Ponds	< 10 - 1,900	< 1 - 102	12,000 - 88,000	180 - 1,300	150 - 800	< 1 - 1.7	10 - 110,000	< 1 - 290

1 Magnitudes represent ratio of ambient concentration to criterion concentration; for example, a magnitude of 5.0 represents an ambient concentration five times the criterion.

2 Sample size ranges from 11 to 17 depending on location and metal analyzed.

Table 4-4
Frequency and Magnitude of Acute AWQC Exceedences in Silver Bow Creek, 1985 - 1994[1]

Metal	Statistic	SBC7	SBC9A	SBC9B	SBC9C
Cadmium	Number of samples	70	48	47	59
	Percentage exceeding criteria	7	4	4	3
	Magnitude of exceedences	1 - 3	1	1 - 2	1 - 19
Copper	Number of samples	113	91	88	88
	Percentage exceeding criteria	100	100	100	100
	Magnitude of exceedences	3 - 84	3 - 64	4 - 31	1 - 46
Zinc	Number of samples	113	91	88	84
	Percentage exceeding criteria	100	100	100	99
	Magnitude of exceedences	1 - 42	2 - 19	4 - 14	2 - 14

1 Magnitude of exceedence is the measured concentration divided by calculated AWQC. No data presented for acute lead criteria because no exceedences have been documented. Data for reach SBC 8 not presented. Data collection within this reach has been virtually nonexistent.

Source: STORET.

Plots of acute criteria exceedences in an upstream reach (SBC9C) and a downstream reach (SBC7) of Silver Bow Creek through 1991 (Figure 4-2) illustrate the severity of surface water injury: ambient water quality conditions are characterized by multiple exceedences of copper and zinc AWQC that occur annually. These plots demonstrate that Silver Bow Creek has been injured continuously by extreme exceedences of acute ambient water quality criteria.

Tables 4-5a through 4-5d summarize chronic criteria exceedences for cadmium, copper, lead, and zinc. These tables show that ambient conditions in Silver Box Creek are characterized by concentrations of hazardous substances that exceed chronic water quality criteria (again, an exceedence of chronic criteria is demonstrated by a magnitude greater than 1.0 over the averaging period). When assessing the combined exceedences of cadmium, copper, lead, and zinc, exceedences occur yearly in all reaches of Silver Bow Creek (where data are available). Therefore injury, defined as exceedences of chronic criteria more than once in a three-year period, is confirmed.

4.2.2.4 Injury to the Clark Fork River

As in Silver Bow Creek, data collected from the Clark Fork River from 1970 to the present demonstrate injury to surface water by exceedences of both acute and chronic ambient water quality criteria.

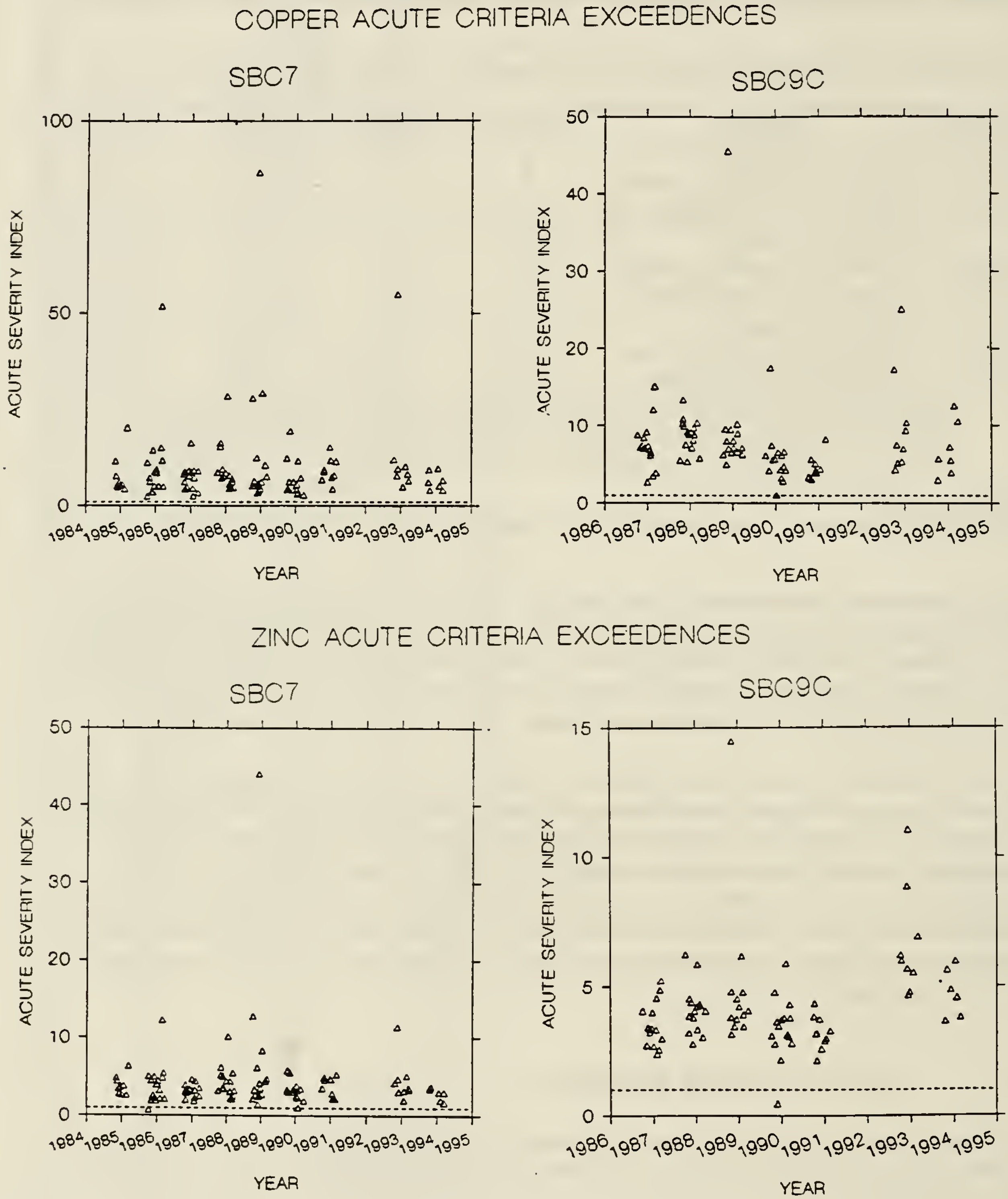


Figure 4-2. **Copper and Zinc Acute Severity Indices, Reaches SBC7 and SBC9C.** Index values greater than one (the dotted line in each figure) indicate concentrations in excess of ambient water quality criteria.

Table 4-5a
Mean Cadmium Chronic AWQC Exceedences in Silver Bow Creek[1]

Reach	Year					
	1989	1990	1991	1992	1993	1994
SBC7	2.6 (6)	1.3 (5)	1.7 (5)	ND	2.1 (5)	1.3 (5)
SBC9A	2.1 (6)	1.3 (5)	1.3 (5)	ND	ND	ND
SBC9B	1.9 (5)	1.5 (5)	1.6 (5)	ND	ND	ND
SBC9C	1.4 (7)	0.9 (5)	0.9 (5)	ND	2.5 (5)	1.4 (5)

1 Value indicates magnitude of chronic criteria exceedence. Value in ( ) is number of samples.

ND = data not available.

Table 4-5b
Mean Copper Chronic AWQC Exceedences in Silver Bow Creek[1]

Reach	Year					
	1989	1990	1991	1992	1993	1994
SBC7	23.4 (6)	12.7 (5)	16.1 (5)	ND	25.0 (5)	11.5 (5)
SBC9A	16.5 (6)	10.5 (5)	11.6 (5)	ND	ND	ND
SBC9B	14.6 (5)	9.9 (5)	10.4 (5)	ND	ND	ND
SBC9C	12.7 (7)	7.4 (5)	6.0 (5)	ND	19.8 (5)	9.0 (5)

1 Value indicates magnitude of chronic criteria exceedence. Value in ( ) is number of samples.

ND = data not available.

Table 4-5c
Mean Lead Chronic AWQC Exceedences in Silver Bow Creek[1]

Reach	Year					
	1989	1990	1991	1992	1993	1994
SBC7	8.5 (6)	4.3 (5)	6.7 (5)	ND	16.1 (5)	6.4 (5)
SBC9A	3.5 (6)	3.0 (5)	4.9 (5)	ND	ND	ND
SBC9B	1.9 (5)	0.9 (5)	3.0 (5)	ND	ND	ND
SBC9C	1.1 (7)	0.5 (5)	2.0 (5)	ND	17.7 (5)	5.1 (5)

1 Value indicates magnitude of chronic criteria exceedence. Value in ( ) is number of samples.

ND = data not available.

Table 4-5d
Mean Zinc Chronic AWQC Exceedences in Silver Bow Creek[1]

Reach	Year					
	1989	1990	1991	1992	1993	1994
SBC7	7.1 (6)	4.0 (5)	4.4 (5)	ND	5.4 (5)	3.5 (5)
SBC9A	5.8 (6)	4.7 (5)	4.4 (5)	ND	ND	ND
SBC9B	6.4 (5)	5.5 (5)	5.7 (5)	ND	ND	ND
SBC9C	4.9 (6)	3.4 (5)	3.1 (5)	ND	8.1 (5)	4.8 (5)

1 Value indicates magnitude of chronic criteria exceedence. Value in ( ) is number of samples.

ND = data not available.

In 1970, the U.S. EPA (1972), as part of the first comprehensive survey of water quality in the Clark Fork River, collected water quality data at locations located in reaches CFR3, CFR5, CFR6B, and CFR6C. Acute copper criteria were exceeded at all stations, and acute zinc criteria were exceeded at stations upstream of the Little Blackfoot River at Garrison. Metals concentrations from this study are summarized in Table 4-6.

Table 4-6
Concentrations of Hazardous Substances and Acute AWQC Exceedences in the Clark Fork River, 1970-1971
(total metals concentrations in µg/l)

Location	Copper		Zinc	
	Concentration Range	Magnitude of Criteria Exceedences	Concentration Range	Magnitude of Criteria Exceedences
Dempsey (CFR6C)	40 - 400	0.6 - 6.1	90 - 960	0.2 - 2.5
Deer Lodge (CFR6B)	20 - 1,200	0.3 - 18.0	70 - 4,700	0.2 - 12.0
Tavenner Bridge (CFR6A)	30 - 460	0.5 - 7.0	60 - 500	0.2 - 1.3
Garrison (CFR5)	20 - 240	0.3 - 3.7	30 - 290	0.1 - 0.8
Drummond (CFR3)	40 - 90	0.6 - 1.4	40 - 250	0.1 - 0.7

Surface water monitoring of the Clark Fork River between 1971 and 1983 was somewhat sporadic, with the exception of the long-term ambient water quality station located at Deer Lodge. This station, located within reach CFR6B, was sampled regularly during this period. By 1985, long-term monitoring programs established by MDHES were collecting samples at least monthly from all reaches of the Clark Fork River except CFR3, CFR5, and CFR6D.

In Figures 4-3 through 4-6, exceedences of acute copper criteria are plotted for a representative reach of the lower, middle, and upper Clark Fork River, and for reach CFR6B (which contains the long-term ambient water quality monitoring station at Deer Lodge). The plots indicate that criteria exceedences have occurred regularly; in most reaches criteria exceedences have been documented almost yearly. Further, the plots show no evidence of a decline in either the frequency or magnitude of criteria exceedences over time. These plots conclusively demonstrate that the entire Clark Fork River has been injured continuously by releases of copper.

Exceedences of chronic copper criteria are tabulated by year (1989 through 1994) and by reach in Table 4-7 (prior to 1989, higher analytical detection limits could lead to some false positive exceedences if detection limits were greater than the chronic criterion). As demonstrated in Table 4-7, in only four reach/years were chronic criteria not exceeded (again, an exceedence of chronic criteria is determined by a magnitude greater than 1.0). None of these four instances were in consecutive years in the same reach. Therefore, injury as defined by exceedences of chronic criteria (exceedence of chronic criteria during a four-day or longer averaging period more than once in a three-year period) has been demonstrated for the Clark Fork River.

The approach for determining injury to the Clark Fork River is conservative for several reasons. First, criteria exceedences for each hazardous substance were evaluated independently of one another. That is, the cumulative frequency of multiple hazardous substance exceedences was not evaluated. Second, injury determination is likely limited by the ability of small datasets (i.e., lack of monitoring intensity) to detect criteria exceedences. (For example, more intensively monitored reaches exhibit more criteria exceedences than reaches in which little or no monitoring has been conducted over time). Finally, much of the data used to evaluate exceedences of ambient water quality criteria were based on the Montana total recoverable method, which can result in a lower concentration than a total recoverable method that uses a hot acid digestion.

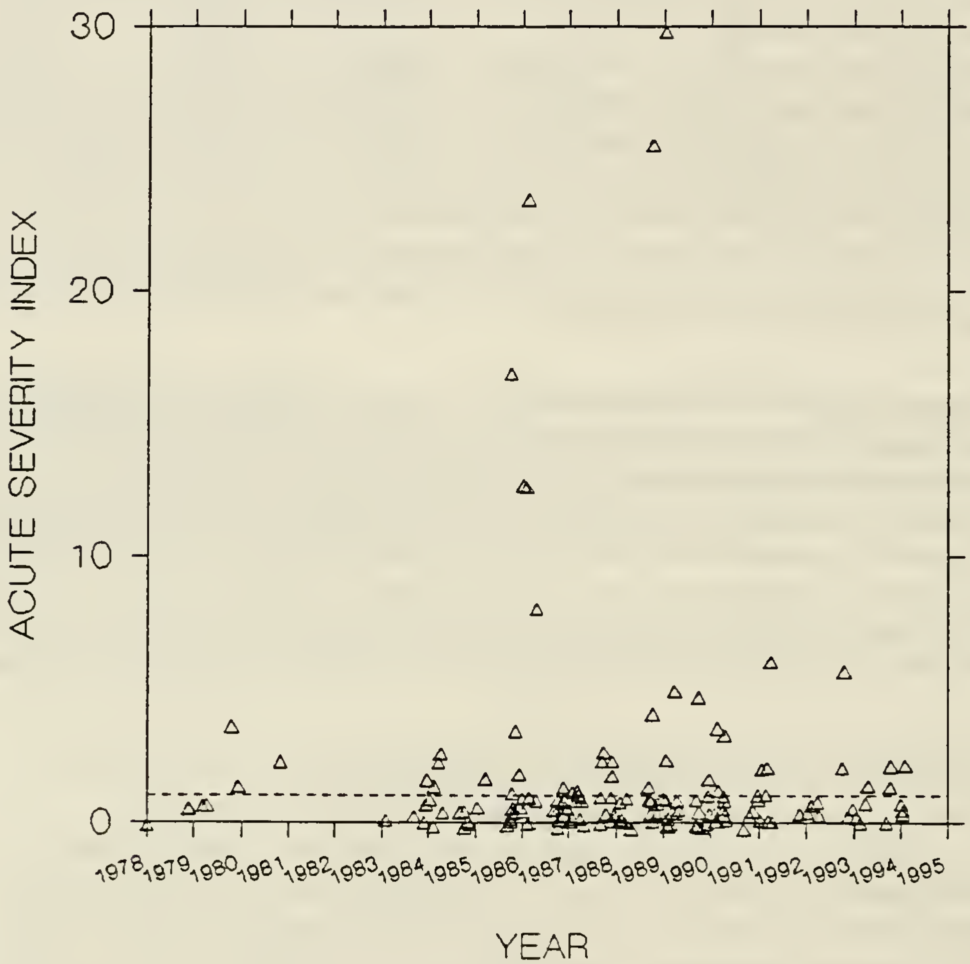


Figure 4-3. Copper Acute Severity Indices, Lower Clark Fork River (Reach CFR1). Index values greater than one (dotted line) indicate concentrations in excess of ambient water quality criteria. Values that appear as symbols below the y-axis are actually slightly greater than zero.

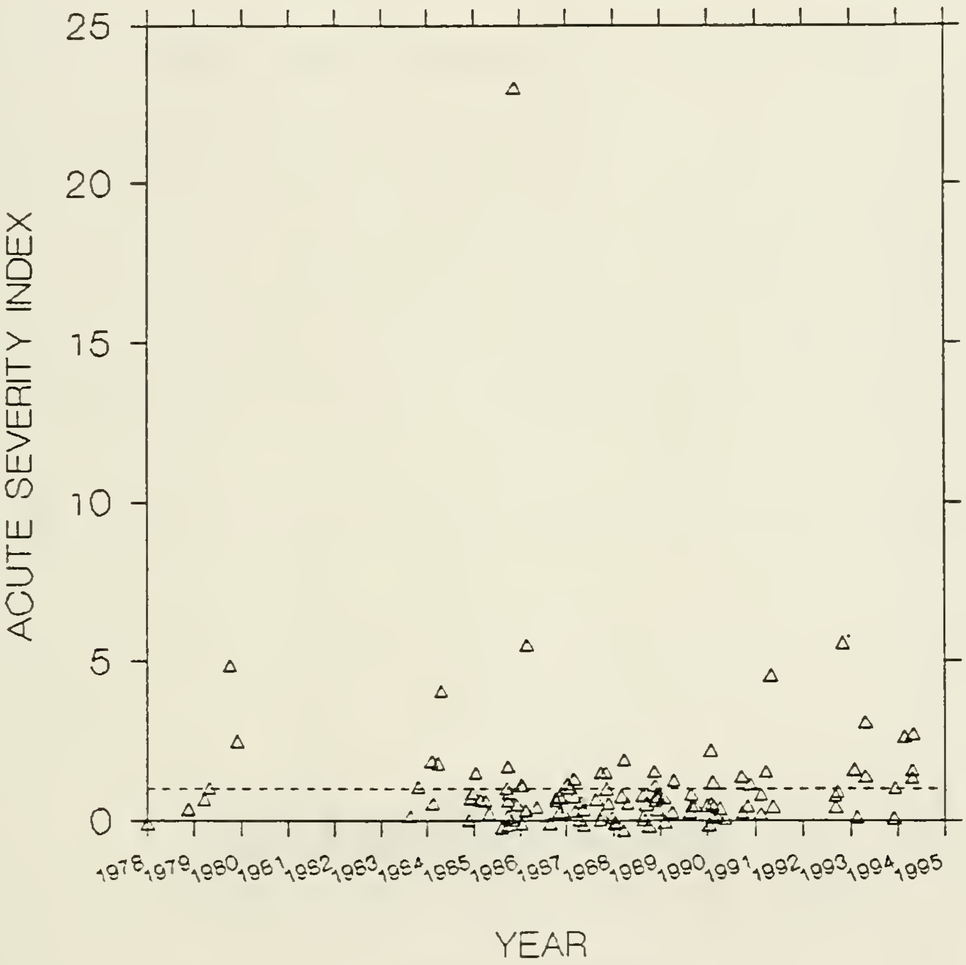


Figure 4-4. Copper Acute Severity Indices, Middle Clark Fork River (Reach CFR4). Index values greater than one (dotted line) indicate concentrations in excess of ambient water quality criteria. Values that appear as symbols below the y-axis are actually slightly greater than zero.

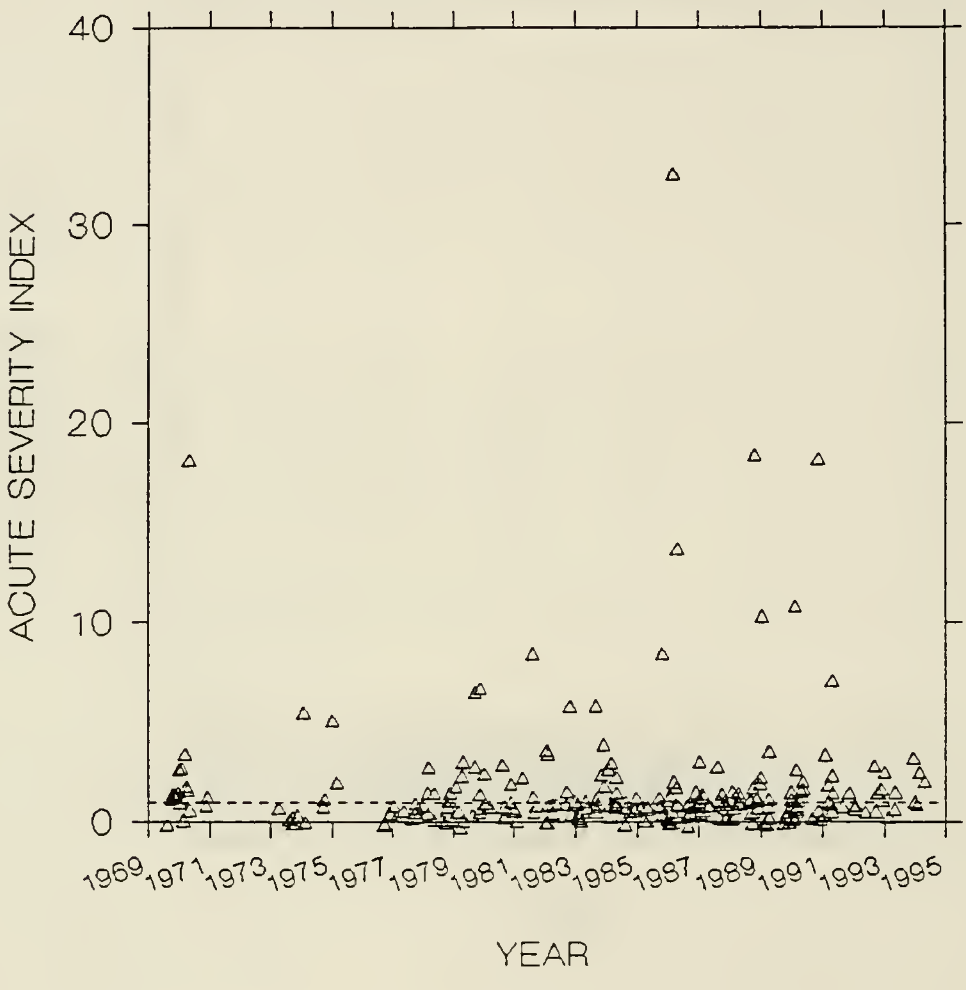


Figure 4-5. Copper Acute Severity Indices, Upper Clark Fork River (Reach CFR6B). Index values greater than one (dotted line) indicate concentrations in excess of ambient water quality criteria. Values that appear as symbols below the y-axis are actually slightly greater than zero.

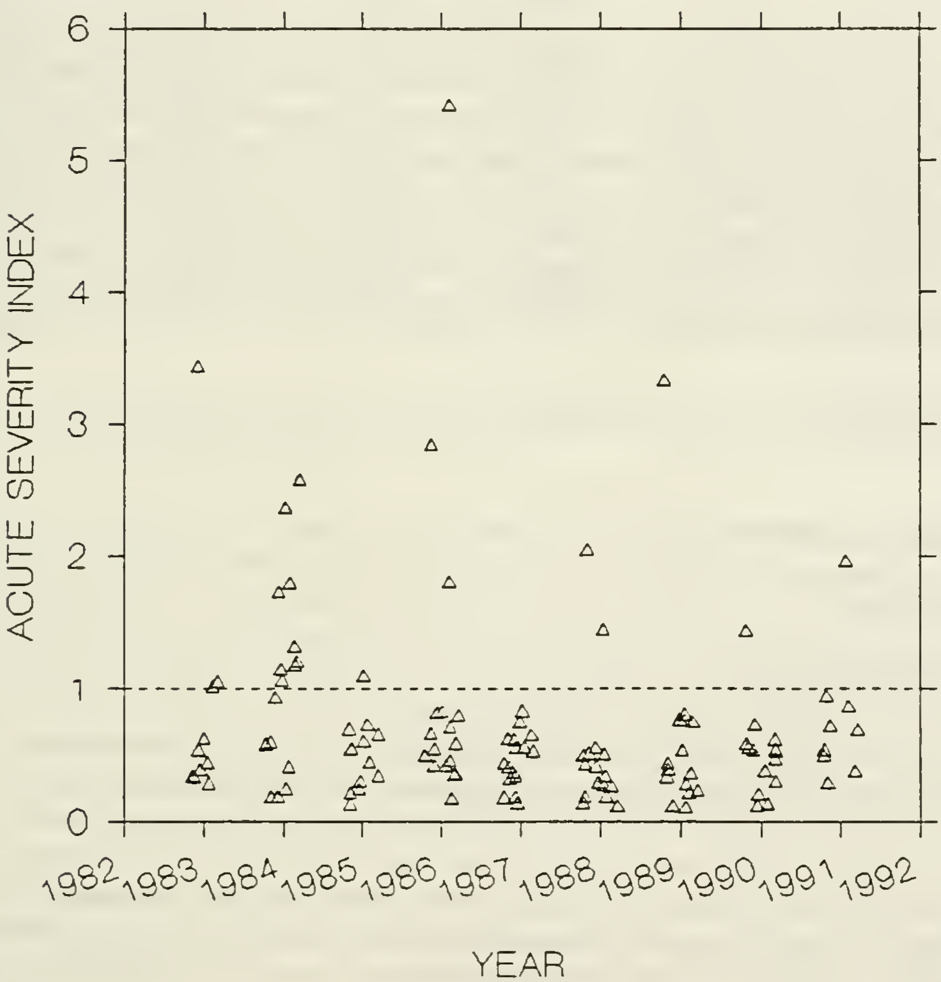


Figure 4-6. Copper Acute Severity Indices, Upper Clark Fork River (Reach CFR6E). Index values greater than one indicate concentrations in excess of ambient water quality criteria.

Table 4-7 Copper Criteria Exceedences (Chronic) in the Clark Fork River[1]						
	Year					
Reach	1989	1990	1991	1992	1993	1994
CFR1	8.8 (12)	2.6 (9)	1.0 (6)	1.1 (2)	3.1 (4)	2.0 (5)
CFR2	0.9 (6)	2.5 (5)	1.5 (5)	ND	ND	ND
CFR4	1.2 (6)	1.1 (5)	1.2 (5)	ND	3.7 (5)	2.7 (5)
CFR6A	1.9 (6)	1.7 (5)	2.2 (5)	ND	ND	ND
CFR6B	5.4 (8)	3.3 (9)	2.1 (7)	1.1 (2)	2.9 (5)	3.6 (4)
CFR6C	1.5 (6)	1.0 (10)	1.3 (10)	ND	ND	ND
CFR6D	6.6 (3)	3.8 (5)	1.9 (2)	1.5 (2)	2.8 (5)	2.2 (4)
CFR6E	1.7 (6)	1.0 (5)	1.1 (5)	ND	ND	ND

1 Value indicates magnitude of chronic criteria exceedence. Value in () is number of samples.

ND = data not available.

4.3 INJURY QUANTIFICATION

4.3.1 Extent of Injury

4.3.1.1 Silver Bow Creek

Silver Bow Creek is injured for its entire length from Butte to Warm Springs Ponds, a distance of approximately 23 miles (37 kilometers). Hazardous substances occur at concentrations that result in continuous injury to the entire resource. Virtually all samples collected from Silver Bow Creek since 1970, including samples collected as recently as 1994, have exceeded both copper and zinc acute ambient water quality criteria. Additionally, as discussed in Chapters 5.0 and 6.0, benthic macroinvertebrates and fish have been injured by exposure to hazardous substances in bed sediments and surface water. It is likely that Silver Bow Creek has been injured for over 100 years.

4.3.1.2 Clark Fork River

The Clark Fork River is injured from its headwaters near Warm Springs to Milltown Reservoir, a distance of approximately 120 miles (190 kilometers). As described previously, copper exceeds both acute and chronic AWQC in all reaches of the Clark Fork River. In

addition, exceedences of chronic AWQC have been observed for zinc and lead. As in Silver Bow Creek, exceedences have been documented virtually every year since 1970, including 1994. Finally, as discussed in Chapter 6.0, fish have been injured by exposure to hazardous substances in surface water. It is likely that the Clark Fork River has been injured for over 100 years.

4.3.2 Severity of Injury (Baseline Comparison)

The baseline comparison is made to assess the severity of injury to surface water. Historical data to assess pre-release baseline conditions in Silver Bow Creek and the Clark Fork River are not available because releases have occurred since the late 1800s (and hence pre-date water quality sampling). For the baseline determination, three former or existing tributaries of Silver Bow Creek were used [43 CFR § 11.72(d)(2)]. For the Clark Fork River, three principal tributaries were used for the baseline comparison. Baseline comparisons are presented below. The baseline comparison for the Clark Fork River is conservative because historic mining activity has occurred in the drainages of the streams used in the baseline analysis.

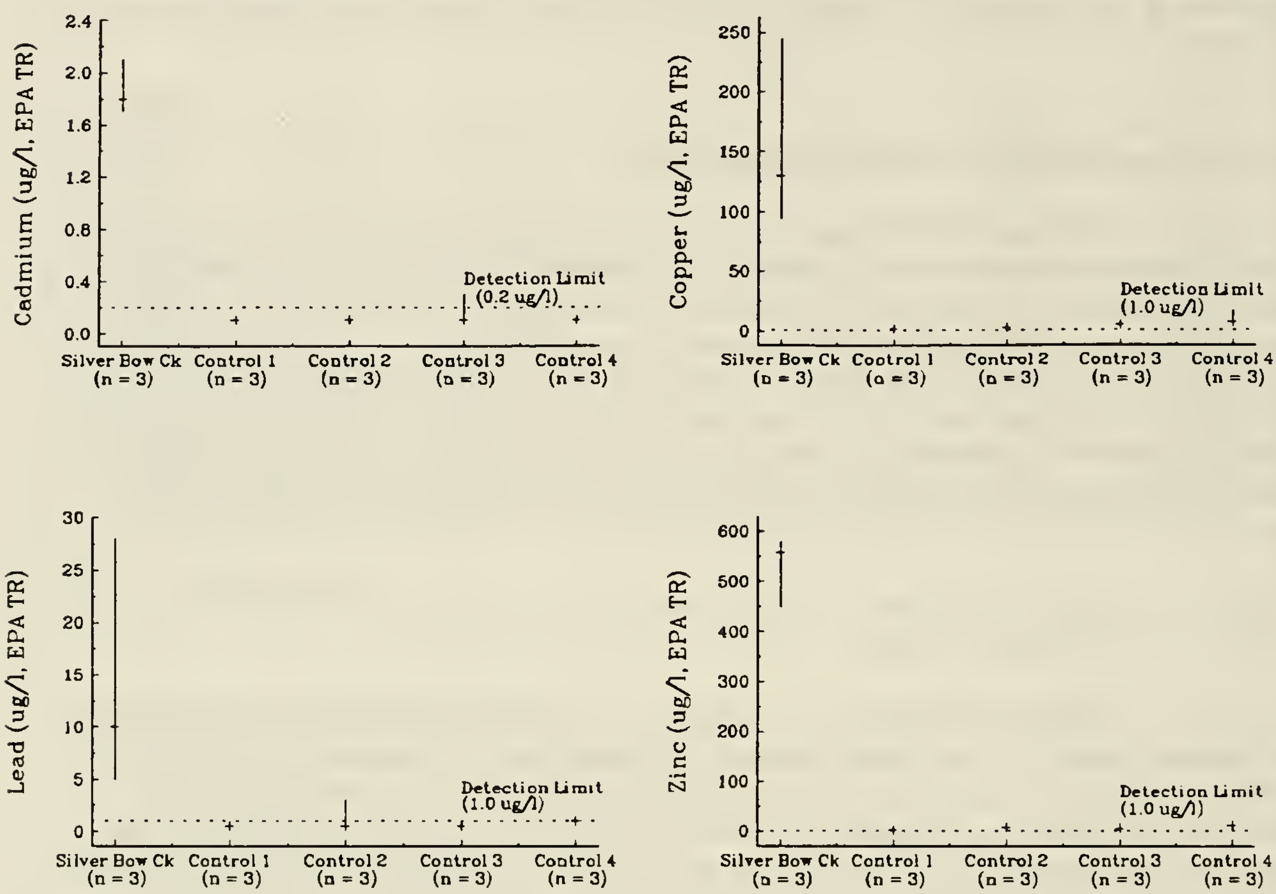
4.3.2.1 Silver Bow Creek

Pre-release concentrations of hazardous substances in Silver Bow Creek can be approximated by the water quality of three streams that are, or formerly were, tributaries to the headwaters of Silver Bow Creek. These three streams are upper Silver Bow Creek, Yankee Doodle Creek, and Blacktail Creek. Upper Silver Bow Creek and Yankee Doodle Creek have been bisected by the Yankee Doodle Tailings and the Berkeley Pit, and are no longer tributaries of Silver Bow Creek. Blacktail Creek is today the major headwater tributary to Silver Bow Creek. These streams are relatively unaffected by mining impacts and are therefore useful in characterizing hazardous substance concentrations which may have existed in Silver Bow Creek prior to releases of hazardous substances.

Cadmium, copper, lead and zinc concentrations (U.S. EPA total recoverable) for Silver Bow Creek and the baseline streams are plotted in Figure 4-7. These plots indicate that concentrations of these metals are significantly elevated in Silver Bow Creek relative to baseline.

4.3.2.2 Clark Fork River

Baseline for the upper, middle, and lower reaches of the Clark Fork River (respectively, Warm Springs Ponds to Little Blackfoot River, Little Blackfoot River to Rock Creek, Rock Creek to Milltown) were evaluated using three principal tributary streams: Warm Springs



Silver Bow Ck = Silver Bow Creek near Ramsey

Control 1 = Silver Bow Creek upstream of Yankee Doodle Tailings

Control 2 = Yankee Doodle Creek upstream of Yankee Doodle Tailings

Control 3 = Blacktail Creek at Thompson Park

Control 4 = Bison Creek at Elk Park

Figure 4-7. Concentrations of Hazardous Substances in 1992 in Silver Bow Creek Headwater Streams (Upper Silver Bow Creek, Yankee Doodle Creek, and Blacktail Creek) and Fish Population Assessment Control Stream (Bison Creek). Values less than the detection limit are plotted as one-half the detection limit. Source: Appendix A.

Creek (control for upper reach), Little Blackfoot River (control for middle reach), and Rock Creek (control for lower reach).

Plots comparing concentrations of hazardous substances in control streams (Warm Springs Creek, Little Blackfoot River, and Rock Creek) with matching reaches of the Clark Fork River are presented in Figures 4-8, 4-9, and 4-10.[3] As shown in these figures and in Table 4-8, concentrations of copper and zinc were significantly greater than baseline at all but two Clark Fork River reaches (CFR3 and CFR6D). Lead concentrations were significantly greater than baseline in reaches CFR1, CFR6A-C, and CFR6E.

4.3.3. Volume of Injury

4.3.3.1 Silver Bow Creek

The volume of injured surface water, based on records for the USGS station located downstream of the Colorado Tailings, averaged 16,291 acre-feet per water year for the years 1984-1990. Annual mean flow is approximately 23 cfs near Lower Area I and approximately 45 cfs near Opportunity (Canonie, 1992). Therefore, the volume of injured surface water in the lower end of Silver Bow Creek is approximately twice the volume discharged near the Colorado Tailings, or approximately 32,580 acre-feet per water year (Table 4-9).

4.3.3.2 Clark Fork River

Continuous USGS discharge records exist for seven stations on the Clark Fork River for varying periods of record. Volumes of injured surface water, in acre-feet per water year, averaged 199,520 at Deer Lodge (1979-1991); 399,840 at Gold Creek (1978-1991); and 773,430 at Turah (1985-1991) (Table 4-9).

4.3.4 Ability of Resource to Recover

The resource recoverability analysis must be made in consideration of response actions performed or anticipated [43 CFR § 11.73 (a)(1)]. For both Silver Bow Creek and the Clark Fork River, it is estimated that response actions will leave a major source of hazardous substances to surface water, floodplain tailings, in place. Response actions underway or anticipated for Silver Bow Creek include (NRDLP et. al., 1995):

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[3] For the baseline comparison, values below the analytical detection limit were set at the detection limit. This approach conservatively treats nondetects from both the impact and baseline streams equally (when the likelihood is that the nondetects in the injured resource represent higher real concentrations than the nondetects in the baseline).

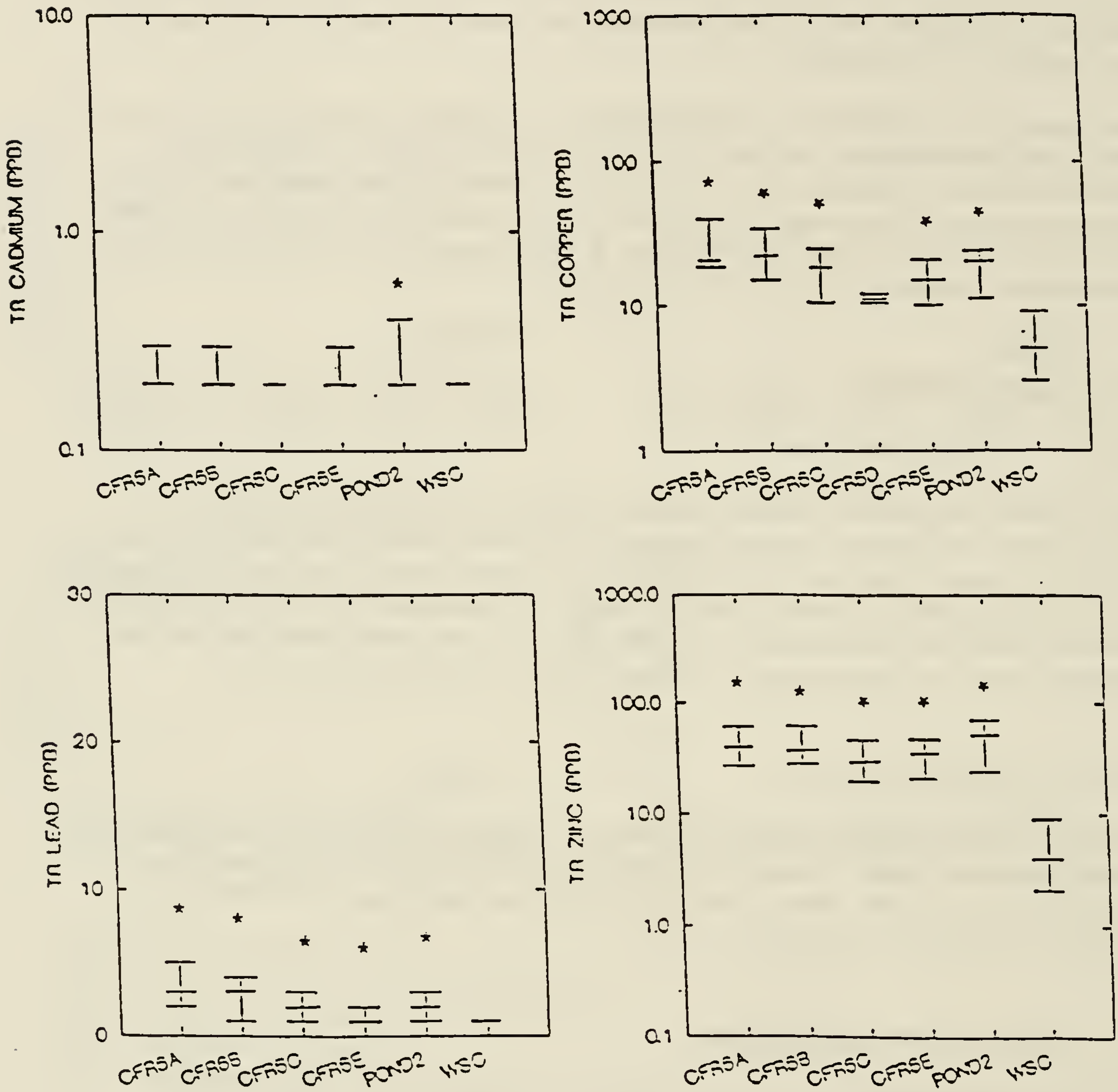

Figure 4-8. Upper Clark Fork River (Reaches CFR6A - CFR6E) and Warm Springs Creek (WSC) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and interquartile range of total recoverable concentrations, in ppb; * indicates significantly greater concentrations in impact reach than in baseline, based on two-sample randomization test.)

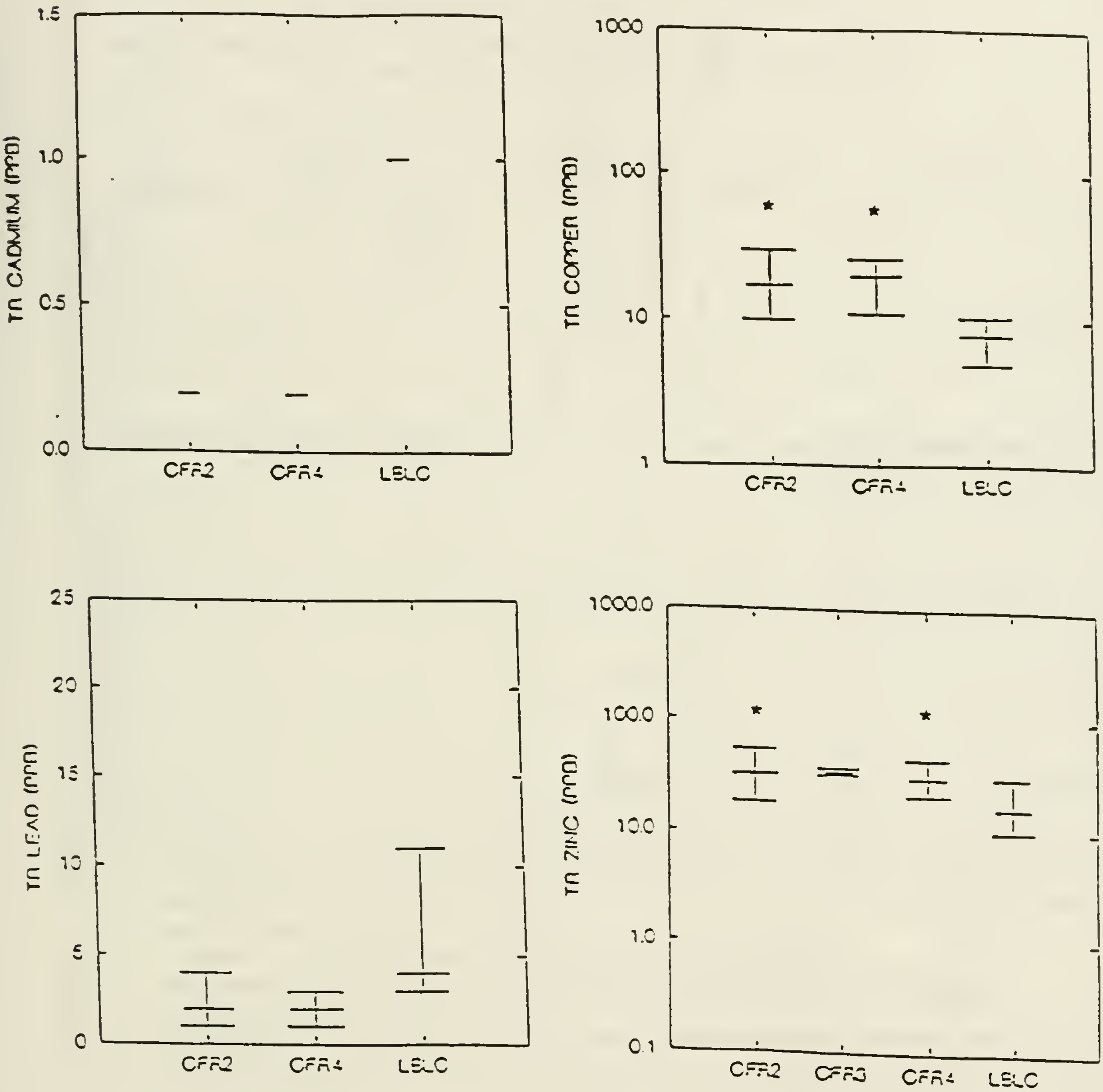

Figure 4-9. Middle Clark Fork River (Reaches CFR2 - CFR5) and Little Blackfoot River (LBLC) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and interquartile range of total recoverable concentrations, in ppb; * indicates significantly greater concentration in impact reach than in baseline, based on two-sample randomization test.)

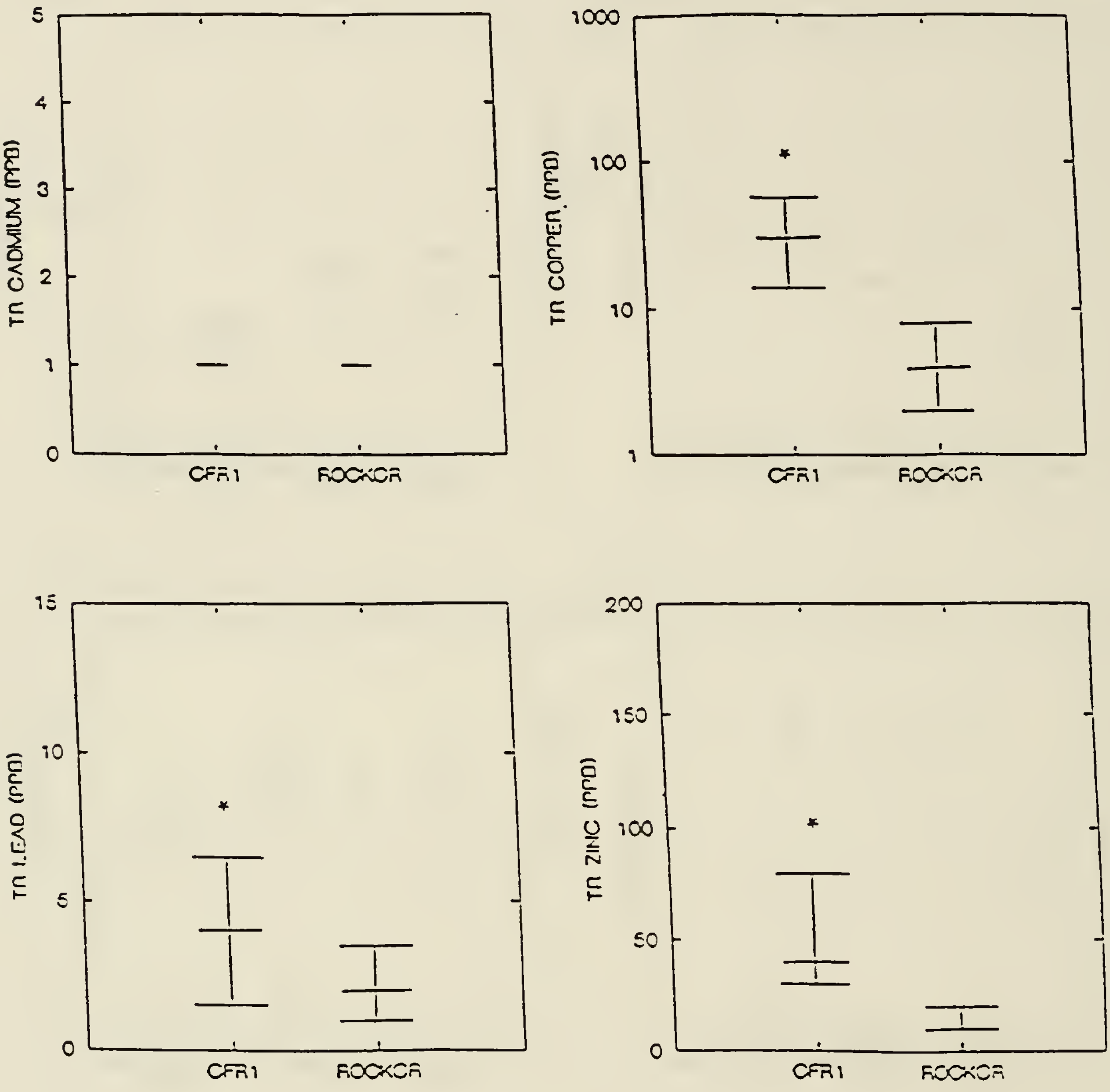

Figure 4-10. Lower Clark Fork River (Reach CFR1) and Rock Creek (ROCKCR) Baseline Comparison for Cadmium, Copper, Lead, and Zinc. (Median and interquartile range of total recoverable concentrations, in ppb; * indicates significantly greater concentration in impact reach than in baseline, based on two-sample randomization test.)

Table 4-8
Two-Sample Randomization Test (Manly, 1991) Comparing Hazardous Substance Concentrations in Clark Fork River to Baseline Conditions (mean difference concentration in µg/l)[1,2]

Impact Reach/Baseline	Cadmium		Copper		Lead		Zinc	
	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value
CFR1/ Rock Creek	0.08	0.2482	61.66	0.0002*	4.00	0.0066*	113.09	0.0002*
CFR2/ L. Blackfoot River	-0.70[3]	0.0002	17.22	0.0002*	-0.81[4]	0.2842	16.05	0.0084*
CFR3/ L. Blackfoot River	NC	NC	8.30	0.1118	NC	NC	6.23	0.3036
CFR4/ L. Blackfoot River	-0.73[3]	0.0002	19.52	0.0002*	-2.03[4]	0.0290	11.67	0.0308*
CFR5/ L. Blackfoot River	NC	NC	NC	NC	NC	NC	NC	NC
CFR6A/ Warm Springs Creek	0.06	0.0548	26.48	0.0002*	3.01	0.0002*	41.11	0.0002*
CFR6B/ Warm Springs Creek	0.03	0.1708	22.73	0.0002*	2.38	0.0002*	43.02	0.0002*
CFR6C/ Warm Springs Creek	0.01	0.3964	15.91	0.0002*	1.44	0.0002*	31.56	0.0002*
CFR6D/ Warm Springs Creek	NC	NC	4.91	0.0774	NC	NC	0.49	0.3628
CFR6E/ Warm Springs Creek	0.09	0.1010	14.39	0.0002*	2.24	0.0042*	45.67	0.0002*
Pond 2 Disch./ Warm Springs Creek	0.11	0.0212*	19.18	0.0002*	3.76	0.0002*	61.15	0.0002*

1 NC = not calculated, no data for impact reaches.
2 Mean difference: positive value indicates higher concentration in impact reach, negative value indicates higher concentration in baseline.
3 Negative value due to higher analytical detection limit in baseline data.
4 Negative value may be partly due to stronger sample digestion methods used in baseline data.

* Indicates significantly greater concentration in impact (Clark Fork River and Silver Bow Creek) at α = 5%.

Table 4-9
Volume of Surface Water Discharged at USGS Stations on Silver Bow Creek (SBC) and the Clark Fork River (CFR)
(units in acre-feet per water year [w] and acre-feet per calendar year [c])[1]

Station Number	Location (Reach)	Period of Record	Minimum	Mean	Maximum
12323250	SBC below Blacktail Creek (SBC9B)	1983-1991	13,650 (w) 14,770 (c)	16,291 (w) 16,463 (c)	20,610 (w) 20,270 (c)
12323750	CFR at Warm Springs (CFR6E)	1973-1979	61,630 (w) 57,590 (c)	105,790 (w) 109,230 (c)	165,200 (w) 178,300 (c)
12323800	CFR at Galen (CFR6D)	1989-1991	67,640 (w) 65,710 (c)	69,810 (w) 69.080 (c)	73,260 (w) 72,450 (c)
12324200	CFR at Deer Lodge (CFR6B)	1979-1991	112,300 (w) 106,800 (c)	199,520 (w) 203,170 (c)	316,100 (w) 326,200 (c)
12323680	CFR at Gold Creek (CFR4)	1978-1991	193,700 (w) 187,700 (c)	399,840 (w) 408,490 (c)	622,500 (w) 636,500 (c)
12331600	CFR at Drummond (CFR3)	1973-1983	289,900 (w) 269,100 (c)	644,000 (w) 650,940 (c)	1,009,000 (w) 1,074,000 (c)
12331900	CFR at Clinton (CFR1)	1980-1990	301,400 (w) 296,000 (c)	602,390 (w) 616,070 (c)	895,400 (w) 917,700 (c)
12334500	CFR at Turah (CFR1)	1985-1991	596,600 (w) 565,800 (c)	773,430 (w) 768,130 (c)	1,048,000 (w) 1,058,000 (c)

[1] Calendar year runs from January 1 through December 31; water year runs from October 1 through September 31.

- Collection and treatment of contaminated groundwater discharges to Silver Bow Creek in the Butte area
- Removal/reclamation of waste dumps and other mining/milling sites in the Butte area
- Collection and treatment of stormwater runoff to Silver Bow Creek
- Partial removal of large tailings impoundments along the upper Silver Bow Creek channel in Butte
- Partial excavation and relocation of tailings and contaminated soils near the Silver Bow Creek channel

- *In situ* treatment (lime stabilization) of floodplain tailings downstream of the Colorado Tailings to the Warm Springs Ponds.

Response actions underway or anticipated for the Clark Fork River include (NRDLP et. al., 1995):

- Reconstruction of the Mill-Willow Bypass around the Warm Springs Ponds

- Upgrading of the Warm Springs Ponds treatment system

- *In situ* treatment (lime stabilization) of streamside tailings downstream of the Warm Springs Ponds to Deer Lodge.

Injuries to the surface water of Silver Bow Creek and the Clark Fork River will remain following completion of these response actions. The Silver Bow Creek and Clark Fork River floodplains contain large volumes of tailings and contaminated soils. Much, if not most, of these tailings and soils will remain in the floodplains and beds of both streams following response actions. Hazardous substances likely will be released to surface water during storm events, snowmelt runoff, and periods of high and overbank flows which will remobilize floodplain tailings and contaminated streambed sediments. When this occurs, surface water concentrations of hazardous substances likely will exceed ambient water quality criteria and baseline conditions. Stream channel migration will also result in the interception of lime-treated floodplain areas by surface water. Due to continuing releases, surface water and bed sediments will remain contaminated and will continue to expose aquatic life (benthic macroinvertebrates and fish). Natural recovery of Silver Bow Creek and the Clark Fork River beyond response actions will proceed extremely slowly. Hazardous substances will not degrade or decompose biologically and will remain in the environment for long periods of time. Thousands of years of natural processes would be required to remove hazardous substances from the Silver Bow Creek and Clark Fork River ecosystems.

4.4 SURFACE WATER CONCENTRATIONS OF HAZARDOUS SUBSTANCES AT FISH POPULATION SITES

Fish population studies were conducted at test sites in Silver Bow Creek and the Clark Fork River, and on control streams (Figure 4-11) (see Chapter 6.0). In order to control for variables that affect fish populations, test and control sites were matched based on a hierarchical classification which included ecological, geological, geomorphic, and hydrologic characteristics (see Chapter 6.0).

Water samples were collected in April and May, 1992 from matched test and control sites. Samples were analyzed for cadmium, copper, lead, and zinc (U.S. EPA total recoverable and dissolved concentrations) (see Appendix A). Metals concentrations were compared using two-

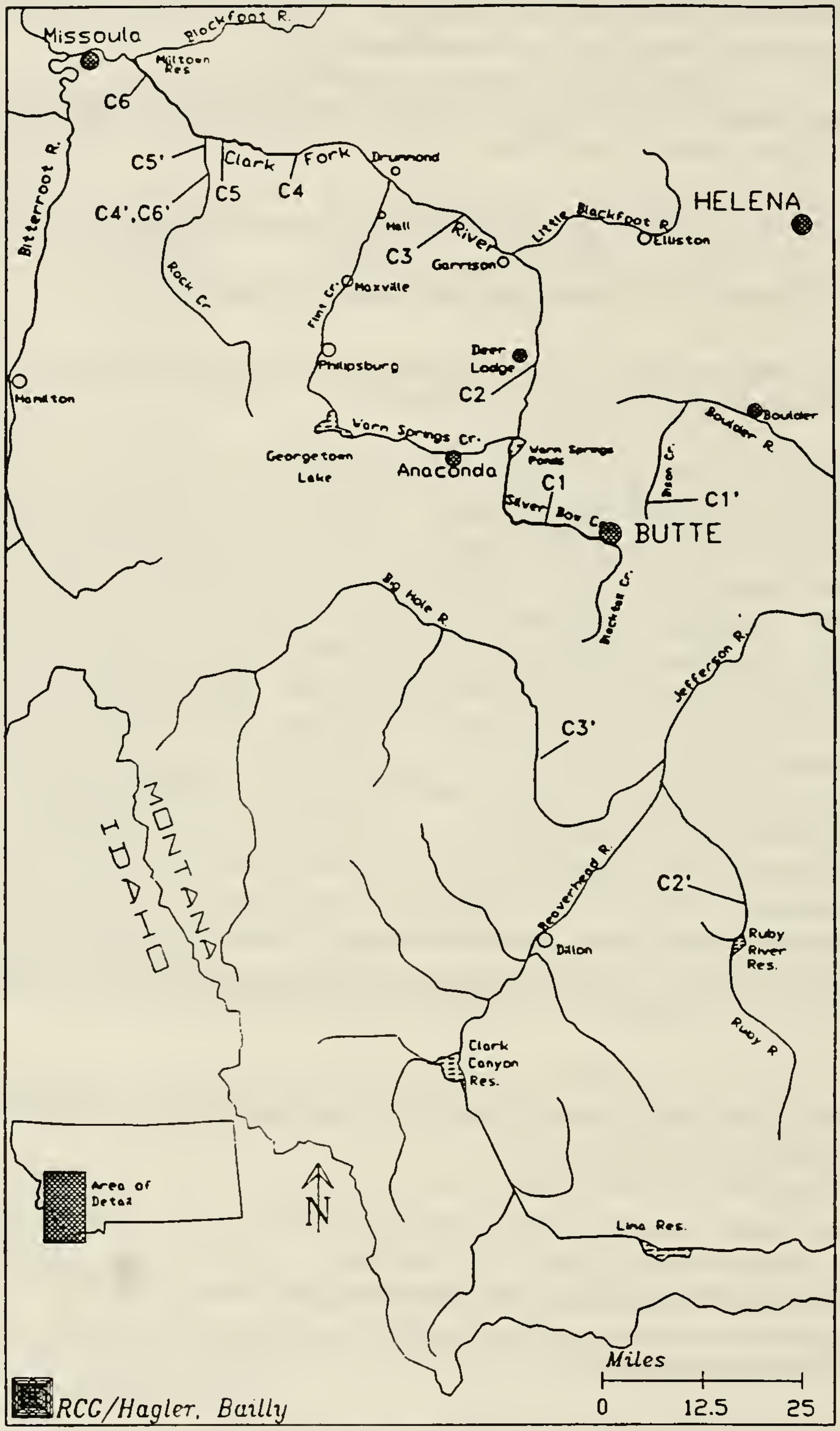

Figure 4-11. Fish Population Sites [impact (C1-C6) and controls (C1'-C6')] at which Surface Water Samples were Collected by NRDLP.

sample randomization tests (Manly, 1991). Tables 4-10 and 4-11 summarize results for comparisons of U.S. EPA total recoverable concentrations (cadmium, copper, lead, and zinc) and dissolved copper and zinc. Dissolved cadmium and lead were not compared because in concentrations were generally not detectable. At the α = 5% level, U.S. EPA total recoverable concentrations of copper, lead, and zinc were significantly greater at all test sites compared to the matched control sites. Cadmium was significantly higher in Silver Bow Creek than in Bison Creek. Dissolved copper was significantly greater in all impact sites than in control sites. Dissolved zinc was significantly greater in Silver Bow Creek and the Clark Fork River at Deer Lodge.

Concentrations of hazardous substances in the Clark Fork River and control sites are plotted in Figure 4-12 (see Figure 4-7 for hazardous substance concentrations in the Silver Bow Creek fishery site and its control, Bison Creek).

4.5 PATHWAYS OF HAZARDOUS SUBSTANCES TO CLARK FORK BASIN SURFACE WATER RESOURCES

The purpose of the pathway determination is to establish the route or media by which hazardous substances were or presently are transported from their sources to surface water resources.

4.5.1 Pathways to Silver Bow Creek

The principal pathways of migration of hazardous substances from their sources to Silver Bow Creek are direct contact (as described in preceding sections), surface water/ sediments pathways, and groundwater pathways. These pathways are described below.

4.5.1.1 Surface Water Pathway to Silver Bow Creek

The principal mechanisms by which surface water transports hazardous substances to other exposed surface waters include surface runoff and riverine transport.

Surface runoff occurs during precipitation and snowmelt events. In the Butte area, surface runoff discharges to Silver Bow Creek through the city of Butte's storm drain system, or by drainage basins in the Butte area. Missoula Gulch, Buffalo Gulch, Anaconda Road-Butte Brewery drainage basin, Idaho Street, West-Side, Warren Avenue, and Grove Gulch all discharge to Silver Bow Creek and contribute to the degradation of Silver Bow Creek (CDM, 1991) (Figure 4-13). Storm-event and snowmelt runoff also remobilize and transport hazardous substances from tailings deposits and other mining wastes directly to Silver Bow Creek along virtually its entire channel from Butte to the Warm Springs Ponds (MultiTech,

Table 4-10
Comparison of Hazardous Substance Concentrations (U.S. EPA total recoverable) at Impact and Control Fish Population Sites in 1992
(mean difference in concentration, µg/l)*

Site Impact/Control	Cadmium		Copper		Lead		Zinc	
	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value
Silver Bow Creek/Bison Creek	1.77	0.05**	146.93	0.05**	13.47	0.0302**	516.17	0.0462**
CFR at Deer Lodge/Ruby River	0.08	0.09	21.37	0.0016**	1.10	0.0262**	23.50	0.0008**
CFR at Gold Creek/Big Hole River	0.07	0.12	19.55	0.0006**	1.92	0.0186**	21.33	0.0028**
CFR at Bearmouth/Rock Creek	0.03	0.22	16.67	0.0012**	1.95	0.0322**	22.58	0.0052**
CFR at Beavertail Hill/Rock Creek	0.02	0.50	15.48	0.0016**	2.15	0.0136**	23.55	0.0050**
CFR at Turah/Rock Creek	0.02	0.50	12.92	0.0042**	1.90	0.0304**	21.92	0.0004**

* Sample size equals 3 for Silver Bow Creek; 6 for all Clark Fork River sites.
** Indicated significantly greater concentration in Silver Bow Creek or the Clark Fork River at $\alpha = 5\%$.
Source: Appendix A.

Table 4-11
Comparison of Hazardous Substance Concentrations (dissolved) at Impact and Control Fish Population Sites (mean difference in concentration, µg/l)* in 1992

Site Impact/Control	Copper		Zinc	
	Mean Difference	p-value	Mean Difference	p-value
Silver Bow Creek/Bison Creek	54.87	0.0474**	324.33	0.0508**
CFR at Deer Lodge/Ruby River	7.42	0.0008**	7.67	0.0034**
CFR at Gold Creek/Big Hole River	3.78	0.0006**	1.68	0.0542
CFR at Bearmouth/Rock Creek	3.22	0.0010**	1.03	0.2142
CFR at Beavertail Hill/Rock Creek	2.88	0.0014**	0.83	0.1912
CFR at Turah/Rock Creek	0.88	0.0166**	0.67	0.2814

* Sample size equals 3 for Silver Bow Creek; 6 for all Clark Fork River sites.
** Indicated significantly greater concentration in Silver Bow Creek or the Clark Fork River at $\alpha = 5\%$.
Source: Appendix A.

1987a, 1987c; CH_2M Hill and Chen-Northern, 1990; CH_2M Hill, 1987). Concentrations of cadmium, copper, lead, and zinc in Butte area storm drain and drainage basin discharges, and surface runoff from tailings deposits are presented in Table 4-12. Butte storm drain runoff exceeds ambient water quality criteria for both copper and zinc by one to two *orders of magnitude*. Runoff from streamside tailings has exceeded chronic criteria by three *orders of magnitude*.

Riverine transport serves as a pathway when hazardous substances are present in the water column either dissolved or adsorbed to suspended sediments. Contaminant transport is most significant during high flows, when bank and channel sediments are remobilized (MultiTech, 1987a).

4.5.1.2 Groundwater Pathway to Silver Bow Creek

Groundwater is an important exposure pathway to Silver Bow Creek. The SBC RI identified contaminated groundwater inflows to Silver Bow Creek in the areas of the Metro Storm Drain, and between Montana Street and the western end of the Colorado Tailings (MultiTech, 1987a). Groundwater quality along the Metro Storm Drain from the Weed Concentrator to near Kaw Avenue is degraded by dissolved arsenic, cadmium, copper, iron, manganese, and zinc (MultiTech, 1987b). The area of degraded water appears to coincide with the location of

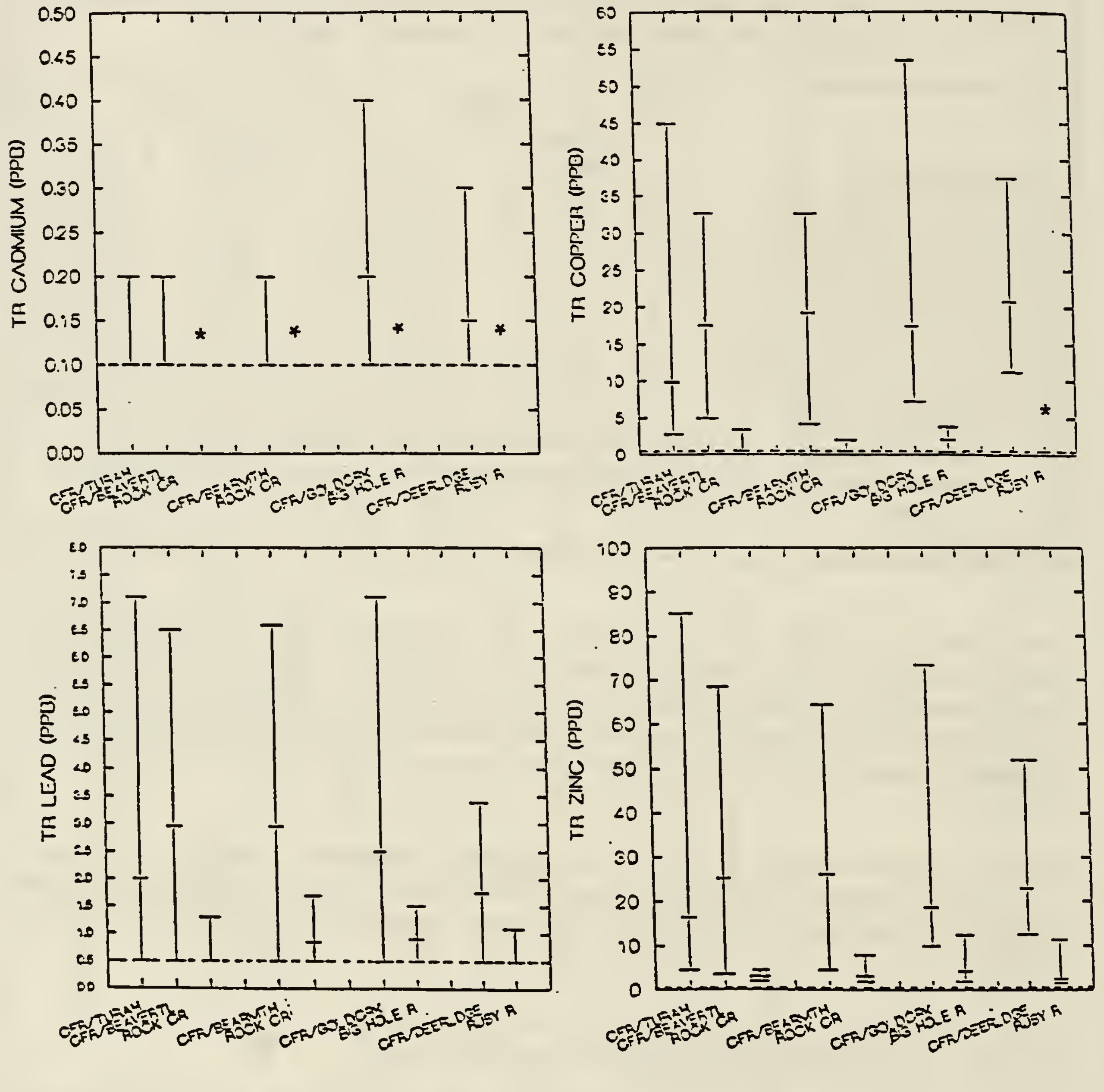

Figure 4-12. Concentrations of Hazardous Substances at Fish Population Impact and Control Sites (U.S. EPA total recoverable concentrations in ppb). Horizontal lines at each site are data minima, medians and maxima. Dotted line represents one-half the analytical detection limit. * denotes sites for which all values were below the detection limit.

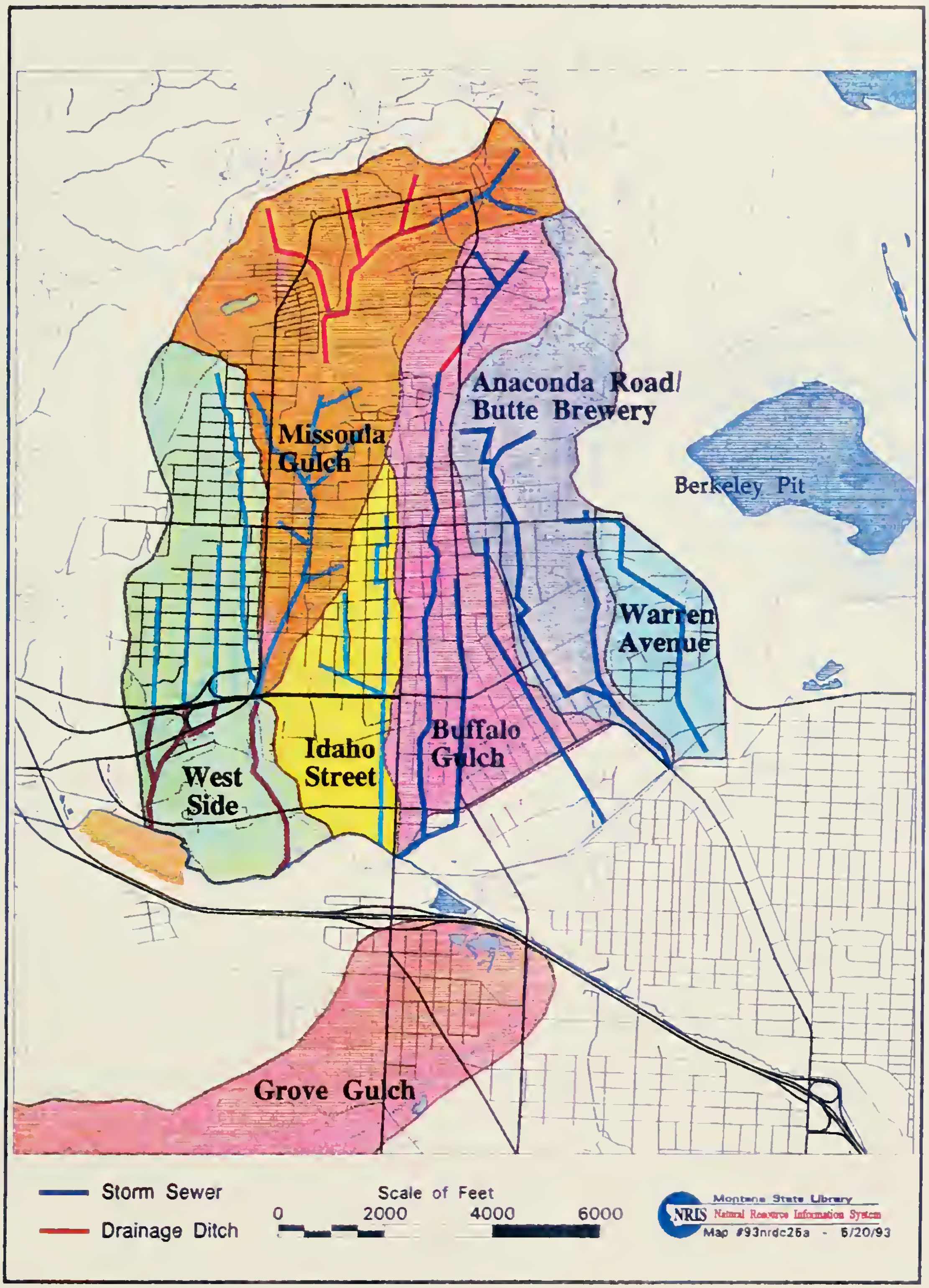

Figure 4-13. Butte Area Stormwater Basins.

Table 4-12
Concentrations of Hazardous Substances in Surface Runoff to Silver Bow Creek
(concentrations in µg/l total recoverable)

Source	Cd	Cu	Pb	Zn
Missoula Gulch				
Snowmelt runoff March 10, 1989[1]	26	611	334	2,190
Storm event May 29, 1985[3]	146	4,020	875	21,300
SBC RI monitoring December 3, 1984[3]	14	916	75	4,340
SBC RI monitoring April 8, 1985[3]	2.9	424	444	2,200
Kaw Avenue storm drain				
Snowmelt runoff March 10, 1989[1]	5	593	267	1,160
Storm event May 29, 1985[3]	25	1,490	448	3,790
Harrison Avenue storm drain				
Snowmelt runoff March 10, 1989[1]	19	2,070	454	3,810
Weed concentrator complex				
Snowmelt runoff March 10, 1989[1]	90	17,400	454	16,800
Metro storm drain				
Snowmelt runoff March 10, 1989[1]	31	2,290	336	3,040
Baseflow sampling September 1988[2]	21	311	5.1	7,370
Storm event May 29, 1985[3]	89	10,600	1,500	9,970
SBC RI monitoring December 3, 1984[3]	36	728	150	1,320
SBC RI monitoring April 8, 1985[3]	3.4	953	13	5,980
SBC RI monitoring July 22, 1985[3]	12	327	9.8	6,260
Colorado tailings				
Snowmelt runoff March 10, 1989[1]	74	21,100*	87	27,200
Storm event runoff July 8, 1986[4]	928	233,000	161	282,000
Ramsay Flats				
Storm event runoff July 16, 1986[4]	1,250	202,000	3,100	264,000
Ambient water quality criteria (acute/chronic) (hardness = 200 mg/l)	8.6/2.0	34.1/21.4	197.3/7.7	210.6/190.7

* Indicates acid soluble concentration.

1 CH_2M Hill and Chen-Northern, 1990.
2 PTI, 1989.
3 MultiTech, 1987a, 1987c.
4 CH_2M Hill, 1987.

the historic Silver Bow Creek channel (MultiTech, 1987b). Alluvial groundwater has been identified as a source of copper and zinc in Silver Bow Creek in the reach between Montana Street and the Colorado Tailings (MultiTech, 1987b, as cited in CDM, 1990). Alluvial groundwater at Lower Area I flows through the Butte Reduction Works and the Colorado Tailings before discharging to Silver Bow Creek (U.S. EPA, 1992). The inflow of metals and arsenic-laden groundwater from the Butte Reduction Works and the Colorado Tailings contributes substantially to exceedences of both acute and chronic ambient water quality criteria for cadmium, copper, and zinc in Silver Bow Creek during baseflow and low flow conditions (CH_2M Hill and Chen Northern, 1990; MultiTech, 1987, as cited in U.S. EPA, 1992).

Recent investigations of the alluvial aquifer along Silver Bow Creek indicate that contaminated groundwater in the area of Miles Crossing (west of Ramsay) discharges to Silver Bow Creek. This groundwater is a pathway of metals migration from streamside tailings to surface water.

Tables 4-13 and 4-14 present metals concentrations in groundwater in Lower Area I and the Colorado Tailings, respectively. These concentrations substantially exceed ambient water quality criteria.

Table 4-13
Concentrations of Hazardous Substances in Lower Area I Wells, Compared to AWQC (concentrations in µg/l)[1]

Source	Statistic	As	Cd	Cu	Pb	Zn
17 wells between 0 and 10 feet in depth	Mean Minimum Maximum	282 1.7 2,200	146 0.39 937	23,353 < 1.1 98,000	266 < 0.5 3,520	50,637 29.6 220,000
13 wells between 10 and 40 feet in depth	Mean Minimum Maximum	513 0.6 1,200	77 < 5 540	1,370 < 1.1 17,000	20.3 < 0.5 180	25,188 < 20 160,000
Ambient water quality criteria (hardness = 200 mg/l)	Acute Criterion Chronic Criterion	360 190	8.6 2.0	34.1 21.4	197.3 7.7	210.6 190.7

[1] U.S. EPA, 1992.

Table 4-14
Maximum Concentrations of Hazardous Substances in Groundwater Beneath the Colorado Tailings
(dissolved concentrations in µg/l)

Well Number (depth)		As	Cd	Cu	Pb	Zn
BMW-2T (4 feet)		0	510	98,000	45	170,000
BMW-2A (16 feet)		5,000	340	20,000	180	110,000
BMW-2B (50 feet)		4,100	790	68,000	15	240,000
Ambient water quality criteria	Acute Criterion	360	8.6	34.1	197.3	210.6
(hardness = 200 mg/l)	Chronic Criterion	190	2.0	21.4	7.7	190.7
Source: CH_2M Hill and Chen-Northern, 1990.						

Table 4-15 presents estimated metals loadings to Silver Bow Creek from groundwater recharge. The importance of the groundwater pathway is demonstrated by its contribution to the total metals loading to the creek. For example, copper loading from groundwater in the area of Montana Street (7.5 pounds per day) represents a 379% increase in the copper loading to Silver Bow Creek from sources upstream (a contribution greater than 100% indicates that loading in a stream reach from groundwater discharge is greater than the load in the stream reach upstream of the groundwater discharge area).

4.5.2 Pathways to the Clark Fork River

The principal pathways of migration of hazardous substances from sources to the Clark Fork River are surface water/sediments and groundwater. These pathways are described below.

4.5.2.1 Surface Water Pathway to the Clark Fork River

The Warm Springs Ponds were built to collect mining-related wastes and associated contaminated sediments transported by Silver Bow Creek from sources in the Butte area. Ponds 1 and 2 were built prior to 1920; Pond 3 was constructed between 1954 and 1959 (Hydrometrics, 1983a, as cited in MultiTech, 1987a). Prior to construction of the Ponds, Silver Bow Creek discharged wastes directly to the Clark Fork River.

Presently, the Warm Springs Ponds discharge to the Clark Fork River by way of the Mill-Willow Bypass. The discharge is a pathway for hazardous substances in Silver Bow Creek and Warm Springs Ponds. Hazardous substance concentrations in the Warm Springs Pond 2 discharge (Table 4-16) regularly exceed ambient AWQC. Although Silver Bow Creek is the primary surface water inflow to the Warm Springs Ponds, inflow to the Ponds also includes the contaminated North and South Opportunity Ponds discharges, which average 0.97 cfs and 1.3 cfs respectively (MDHES and CH_2M Hill, 1989).

Table 4-15
Estimated Loadings of Hazardous Substances to Silver Bow Creek from Groundwater (pounds per day)*

Stream Reach	Cd Loading	% Cd Contrib.	Cu Loading	% Cu Contrib.	Pb Loading	% Pb Contrib.	Zn Loading	% Zn Contrib.
Metro storm drain (MSD)[1] area groundwater	0.07	99.4	1.8	25.4	0.01	53.0	22.9	77.1
Montana Street[2] area groundwater	0.11	245	7.5	379	0.03	25.4	19.6	259
Lower Area I[3] groundwater (low flow conditions)	NC	NC	14.5	NC	NC	NC	62.7	NC
Colorado Tailings[2] area groundwater	0.10	147	7.9	68.6	0.01	9.0	39.9	125
Colorado Tailings[4] area groundwater	NC	NC	NC	66	NC	NC	NC	66
Colorado Tailings area (July 1987-June 1988)[5]	NC	NC	15.3	NC	NC	NC	64.7	NC
Colorado Tailings area[6]	NC	NC	NC	> 70	NC	NC	NC	> 70
Colorado Tailings area[7] (August 1989)	0.27	NC	23.5	NC	NC	NC	108	NC

* NC = not calculated.

1 MultiTech, 1987a (loadings during low flow expressed as a percentage of measurements at the confluence of the MSD with Silver Bow Creek).
2 MultiTech, 1987a (loadings during low flow expressed as a percentage of measurements at the stream station above the area of groundwater inflow).
3 U.S. EPA, 1992.
4 Rouse, 1977, as cited in U.S. EPA, 1992.
5 Ingman and Kerr, 1990a.
6 Duaime et al., 1990, as cited in U.S. EPA, 1992.
7 Hydrometrics, 1990.

Warm Springs Creek, Mill Creek, and Willow Creek, though generally considered to be medium to high quality waters, occasionally transport hazardous substances from sources in the Anaconda area to the Clark Fork River. Elevated metals concentrations have been documented in Warm Springs Creek during high flows (Ingman and Kerr, 1990b; ESE Inc., 1991). Historical operating practices at the Old Works included sluicing unknown quantities of concentrator tailings into Warm Springs Creek (Tetra Tech, 1987). Results of hydraulic modeling (PTI, 1991) indicate that erosion and transport of waste deposits in the Old Works near to or within the floodplain of Warm Springs Creek is likely during very high flows.

Table 4-16
Concentrations of Hazardous Substances in the Warm Springs Pond 2 Discharge
(Montana total recoverable concentrations in µg/l)

Year	Cd		Cu		Pb		Zn	
	Range	Median	Range	Median	Range	Median	Range	Median
1983	NA	NA	< 10 - 190	35	NA	NA	20 - 260	90
1984	NA	NA	< 10 - 120	20	NA	NA	20 - 470	120
1985	NA	NA	< 10 - 100	30	NA	NA	15 - 495	132
1986	NA	NA	< 10 - 160	30	NA	NA	19 - 693	54
1987	NA	NA	< 10 - 40	20	NA	NA	7 - 191	43
1988	< 0.2 - 0.3	< 00.2	3 - 30	10	< 1 - 4	< 1	6 - 156	51
1989	< 0.2 - 0.2	< 0.2	7 - 210	20	< 1 - 55	2	10 - 576	58
1990	< 0.2 - 0.4	< 0.2	6 - 57	16	< 1 - 10	1	4 - 115	40
1991	< 0.2 - 0.9	0.4	16 - 49	24	1 - 52	4	43 - 118	61
1992	0.1 - 3.1	1.0	9 - 338	37	1 - 40	6	16 - 484	91
1993	< 0.1 - 30.2	1.0	14 - 554	43	< 1 - 24	5	< 8 - 1551	96
1994[1]	< 0.1 - 0.8	0.4	8 - 33	27	< 1 - 5	3	< 4 - 170	41
Acute criterion[2]	8.6		34.1		197.3		210.6	
Chronic criterion[2]	2.0		21.4		7.7		190.7	

NA = Not available.

[1] Data available through October.
[2] Criteria based on a hardness of 200 mg/l.

Source: STORET, (1983 - 1991); ARCO, (1992 - 1994).

Surface runoff from contaminated soils is the likely cause of degraded water quality in Mill Creek, which flows less than 1 mile from Smelter Hill, (Tetra Tech, 1987). Tailings deposited by Silver Bow Creek in the lower Willow Creek watershed may be a factor in this stream's contamination (Tetra Tech, 1987). Table 4-17 provides examples of metals concentrations in these surface water pathways.

Surface runoff from streamside tailings associated with precipitation events also acts as a surface water pathway. High-intensity storm runoff events from the Mill-Willow Bypass were responsible for several fish kills in the upper Clark Fork River in the 1980s (see Chapter 6.0). MDHES and CH_2M Hill (1989) identified tailings and metal salts in the Mill-Willow Bypass as sources of hazardous substances to the Bypass and the Clark Fork River during thunderstorms.

Table 4-17 Concentrations of Hazardous Substances in Warm Springs Creek, Mill Creek, and Willow Creek Surface Water Pathways to the Clark Fork River (total concentrations in µg/l)					
Location	**Number of Samples**	**Arsenic**	**Copper**	**Lead**	**Zinc**
Warm Springs Creek					
Range		3 - 10	1.3 - 24	< 3 - 6	< 3 - 22
Geometric Mean	24	< 5.2	< 5.4	< 3.3	< 6.9
Mill Creek					
Range		10 - 32	< 1.3 - 12	< 3 - 8	< 3 - 20
Geometric Mean	12	21	< 4.8	< 3.6	< 8.8
Willow Creek					
Range		30 - 62	< 1.3 - 28	3 - 17	10 - 35
Geometric Mean	4	42	< 7.6	5.3	24
Source: Tetra Tech, 1987.					

Riverine transport is the primary transport mechanism of hazardous substances from upstream sources to downstream reaches in the Clark Fork River. ENSR (1992) estimate that average annual sediment deposition in the Milltown Reservoir was approximately 10,000 tons per year over a 51-year simulation period. Lambing (1991) estimated that Milltown Reservoir sediment deposition was approximately 16,300 tons per year during water years 1985-1990.

4.5.2.2 Groundwater Pathway to the Clark Fork River

Groundwater samples collected during the Warm Springs Ponds RI identified degraded groundwater in the shallow aquifer underneath and below Pond 1 (ESA, 1991). Metals concentrations in samples collected from shallow (generally less than 15 feet) and deep (generally 15 to 40 feet deep) wells in the Pond 1 area and below are presented in Table 4-18. This groundwater discharged hazardous substances, most notably zinc, to the Clark Fork River at a rate of approximately 1 cfs (MDHES and CH_2M Hill, 1989). This groundwater will be collected and pumped back through the pond system for treatment following remediation of Pond 1.

Table 4-18
Concentrations of Hazardous Substances in Groundwater Pathway to the Clark Fork River Below Warm Springs Ponds (µg/l)

Description	As	Cd	Cu	Pb	Zn
Shallow Wells (generally < 15 feet deep)					
Maximum	197.0	12.7	15.9	< 2.0	253
Minimum	< 2.0	< 5.0	< 6.0	< 1.0	16.3
Average	28.0	3.6	5.8	2.0	89.0
Deep Wells (generally 25 to 40 feet deep)					
Maximum	< 3.0	8.4	< 8.0	< 2.0	43
Minimum	< 2.0	< 5.0	< 6.0	< 1.0	6.2
Average	1.0	4.3	3.5	0.8	19.8

Source: MDHES and CH_2M Hill, 1989.

The combined flows of Mill and Willow Creeks were historically degraded in the Mill-Willow Bypass by discharge of contaminated groundwaters from Opportunity Ponds and Warm Springs Ponds. Although groundwater quality beneath Ponds 2 and 3 was not investigated during the RI, wells located between the Ponds and the Mill-Willow Bypass contained elevated concentrations of hazardous substances compared to upgradient monitoring wells (Table 4-19). Approximately 2.5 cfs of groundwater from the Warm Springs Ponds discharged to the Mill-Willow Bypass (MDHES and CH_2M Hill, 1989). Another 0.7 cfs of groundwater from the Opportunity Ponds area was calculated to recharge to the Bypass. The combined inputs of these groundwater inflows increase hazardous substance loadings along the Bypass by approximately 30% during baseflow conditions of 13 cfs (MDHES and CH_2M Hill, 1989). Excavation and reconstruction of the Mill-Willow Bypass included installation of a collection system to intercept groundwater discharging through the ponds to the Bypass.

The Bypass reconstruction is nearing completion. The effectiveness of the reconstruction in alleviating degradation of surface water in the Bypass has not yet been evaluated by U.S. EPA.

Groundwater from beneath the Opportunity Ponds also recharges to Warm Springs Creek. Less than 2 cfs of groundwater discharges directly to the creek; 3-5 cfs discharges via the North Drain (Tetra Tech, 1987). This groundwater recharge alone probably does not have a significant impact on hazardous substance concentrations in Warm Springs Creek (Tetra Tech, 1987), but is nonetheless another pathway by which metals migrate to the Clark Fork River.

Table 4-19 Concentrations of Hazardous Substances in Groundwater Along the Mill-Willow Bypass Compared to Upgradient Groundwater (µg/l)					
Description	**As**	**Cd**	**Cu**	**Pb**	**Zn**
Shallow Wells (generally < 15 feet deep)					
Maximum	41.0	11.7	15.0	18.0	1250
Minimum	< 2.0	< 5.0	< 6.0	< 1.0	12.7
Average	9.2	3.7	4.6	2.5	265
Deep Wells (generally 25 to 40 feet deep)					
Maximum	< 2.0	5.2	7.1	2.0	38.0
Minimum	< 2.0	< 5.0	< 6.0	< 1.0	6.2
Average	1.1	2.9	4.0	1.1	22.2
Upgradient wells					
Maximum	6.8	7.0	9.7	1.2	21.2
Minimum	2.6	< 5.0	6.1	< 1.0	4.7
Average	4.3	3.4	5.8	0.84	10.3
Source: MDHES and CH_2M Hill, 1989.					

4.6 SUMMARY

Surface waters of Silver Bow Creek are injured by the hazardous substances cadmium, copper, lead and zinc, as demonstrated by exceedences of acute and/or chronic ambient water quality criteria for these substances. The severity of injury to Silver Bow Creek is demonstrated by the frequency and magnitude of criteria exceedences. Virtually all samples collected from Silver Bow Creek since 1985 have exceeded acute water quality criteria for copper and zinc. Copper concentrations as much as 84 times the acute criterion, and zinc concentrations as much as 42 times the acute criterion, have been documented. Exceedence of copper chronic criteria by a factor of 10 to 20 is common throughout Silver Bow Creek. Cadmium, lead, and zinc also exceed chronic ambient water quality criteria

Surface waters of the Clark Fork River are injured by the hazardous substance copper, as demonstrated by exceedences of both acute and chronic ambient water quality criteria. Exceedences of 2 to 5 times acute criteria are typical throughout the Clark Fork River. Copper chronic criteria are also exceeded throughout the Clark Fork River. Concentrations of lead and zinc, in addition to copper, are greater in the Clark Fork River than in control and tributary streams. These substances constitute a pathway to other aquatic resources, particularly trout, that live in the Clark Fork River (see Chapter 6.0).

Injury to the surface waters of Silver Bow Creek and the Clark Fork River represent a single harm caused by multiple exposures to hazardous substances. Multiple exceedences, by multiple hazardous substances, of ambient water quality criteria occur virtually every year. Thus, surface waters are injured. Exceedences of ambient water quality criteria are documented as far back as 1970, and as recently as the present time. Releases of hazardous substances to Silver Bow Creek and the Clark Fork River have occurred for approximately 100 years. It is likely that surface water resources have been injured for a similar length of time.

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5.0 BENTHIC MACROINVERTEBRATES

5.1 INTRODUCTION

Benthic macroinvertebrates are invertebrates that live principally on stream or lake bottoms. They span a wide range of life histories and ecologies, from plant-eating "scrapers" to predators that prey on other invertebrates. Many are the larval, or juvenile stages, of insects and emerge from the stream or lake as flying or terrestrial adults. Benthic macroinvertebrates are essential in nutrient and energy cycling in aquatic ecosystems and are integral components of the aquatic food chain (ASTM E 1383-1390, as cited in U.S. FWS and University of Wyoming, 1992). They are the primary food source for many fish species, including trout (U.S. EPA, 1989a; Stolz and Schnell, 1991).

Benthic macroinvertebrates have been used extensively to monitor the effects of metals contamination on riverine systems. They are useful in biomonitoring for several reasons: (1) they are in intimate contact with contaminated sediments; (2) they exhibit a wide range of sensitivity to metals; (3) they occupy limited home ranges; (4) they are integral components of the aquatic food chain; (5) they integrate exposure conditions over their lifespans (typically several months to a few years); and (6) they are relatively easy to monitor (Wiederholm, 1984; U.S. EPA, 1989a; U.S. EPA, 1989b; Voshell Jr. et al., 1989; Burton, 1992; Cairns and Pratt, 1993). Metals, including arsenic, cadmium, copper, lead, and zinc, have been shown to be toxic to benthic macroinvertebrates in laboratory toxicity tests (U.S. EPA, 1992), artificial laboratory streams (Clements et al., 1988; Clements et al., 1992; Clements et al., 1989; Kiffney and Clements, 1994; Selby et al., 1985), natural streams experimentally dosed with metals (Winner et al., 1975, as cited in Clements, 1991; Winner et al., 1980; Leland, 1985, as cited in Clements, 1991; Leland et al., 1989), and in streams or rivers receiving metal pollution (for a review, see Clements, 1991).

In this chapter, two distinct topics relating to benthic macroinvertebrates are presented:

1. In Silver Bow Creek and in the Clark Fork River, benthic macroinvertebrates have been exposed to and have accumulated hazardous substances (Section 5.2). Because of this accumulation, benthic macroinvertebrates are a critical pathway by which fish are exposed to, and injured by, hazardous substances (see Chapter 6.0).

2. In Silver Bow Creek, benthic macroinvertebrates have been injured as a result of exposure to hazardous substances in contaminated streambed sediments (Section 5.3).

5.2 BENTHIC MACROINVERTEBRATES AS A PATHWAY TO FISH: ACCUMULATION OF HAZARDOUS SUBSTANCES

Benthic macroinvertebrates can accumulate metals from contaminated environments (Smock, 1983a; Hare et al., 1991; Power and Chapman, 1992; Rainbow and Dallinger, 1993; Timmermans, 1993). Metal accumulation can occur via several routes: (1) from surface water through both adsorption to the exoskeleton (Smock, 1983b; Krantzberg and Stokes, 1988) and uptake across the gills and other external body parts (Dodge and Theis, 1979, as cited in Gower and Darlington, 1990; Koselwat and Knight, 1987, as cited in Gower and Darlington, 1990; Hare et al., 1991); and (2) from sediments and food (including periphyton, which is plant material that grows on submerged surfaces) via uptake across the gut (Burrows and Whitton, 1983; Smock, 1983a; Selby et al., 1985; Gower and Darlington, 1990; Hare et al., 1991).

Since benthic macroinvertebrates are the primary food source for many fish species, metals that accumulate in benthic macroinvertebrates can be directly passed on to fish. Chapter 6.0 of this report details injuries to fish caused by consumption of contaminated benthic macroinvertebrates from the Clark Fork River.

5.2.1 Silver Bow Creek Benthic Macroinvertebrate Hazardous Substances Tissue Concentrations

Concentrations of hazardous substances in Silver Bow Creek benthic macroinvertebrate tissues were measured in a study by the U.S. FWS and the University of Wyoming conducted as part of a U.S. EPA Superfund Remedial Investigation (U.S. FWS and University of Wyoming, 1992). Hazardous substances were measured in macroinvertebrates collected from Silver Bow Creek near Warm Springs Ponds and from a control stream (Rock Creek) (Table 5-1). In addition, hazardous substance concentrations were measured in the amphipod *Hyalella azteca* after being exposed in the laboratory for 28 days to sediments that were collected from stations in Silver Bow Creek and Rock Creek (control) (Table 5-1). During the 28-day laboratory exposure, a significantly higher number of amphipods exposed to Silver Bow Creek sediments died than amphipods exposed to control sediments. Since only the amphipods that survived the test were analyzed for hazardous substances, the reported tissue concentrations may underestimate the extent to which hazardous substances accumulate in amphipods exposed to Silver Bow Creek sediments.

Differences in mean concentrations in field-collected macroinvertebrates from Silver Bow Creek and the control stream (Rock Creek) were compared using two-sample randomization tests (Manly, 1991). Concentrations of hazardous substances in macroinvertebrates collected from Silver Bow Creek were found to be significantly higher than those from the control stream (Table 5-1). Bioaccumulation of hazardous substances from Silver Bow Creek sediments was also confirmed in the controlled laboratory uptake experiments, although sample sizes were not large enough for statistical testing.

Table 5-1
Mean Metals Concentrations in Benthic Macroinvertebrates, Silver Bow Creek and Control

Organism	Location	Hazardous Substance Concentration (ppm dry weight)				
		Arsenic	Cadmium	Copper	Lead	Zinc
Field-collected invertebrates	Silver Bow Creek	34.1*	8.38*	1382*	67.1*	1665*
	Control (Rock Creek)	2.7	0.13	26	0.54	212
Lab-exposed amphipods (no statistics performed)	Exposed to Silver Bow Creek sediment	7.44	2.04	249	7.27	259
	Exposed to control sediment (Rock Creek)	0.39	1.66	80	0.87	57

* Statistically significant at $p < 0.05$ (vs. control).

Source: U.S. FWS and University of Wyoming, 1992.

5.2.2 Clark Fork River Benthic Macroinvertebrate Hazardous Substances Tissue Concentrations

Chapter 6.0 describes studies that demonstrate injury to fish caused by consumption of hazardous substance-contaminated macroinvertebrates collected from the Clark Fork River. Fish that were fed diets consisting of contaminated macroinvertebrates had reduced survival, decreased growth, and physical deformations relative to fish fed control diets. These studies demonstrate the importance of the food chain pathway in causing injury to fish in the Clark Fork River.

Several investigations have been conducted on accumulation of hazardous substances in Clark Fork River benthic macroinvertebrates, including those by the USGS in 1986 (Cain et al., 1992, raw data in USGS, 1992) and 1993 (Lambing et al., 1994), the U.S. FWS and University of Wyoming (1992) in 1991, and by Boggs (1994) in 1991-2. These investigations measured hazardous substance concentrations in macroinvertebrates collected from different stations along the Clark Fork River. Macroinvertebrates were also collected from tributaries to the Clark Fork River that served as control areas: USGS (1992) collected samples from Rock Creek and the Blackfoot River for use as controls; U.S. FWS and the University of Wyoming (1992) used samples from Rock Creek as controls; and Lambing et al. (1994) used samples from Rock Creek and the Blackfoot River as controls. The U.S. FWS and University of Wyoming study also measured hazardous substance concentrations in the amphipod

Hyalella azteca exposed for 28 days in the laboratory to sediments that were collected from the same Clark Fork River and control stations from which macroinvertebrates were collected.

Tables 5-2 and 5-3 and Figures 5-1 through 5-9 present the hazardous substance concentrations measured in field-collected benthic macroinvertebrates. In the U.S. FWS and University of Wyoming study, macroinvertebrates of a variety of taxa that were representative of the benthic community were collected and composited for analysis of hazardous substances. The USGS (USGS, 1992; Lambing, 1994) and Boggs (1994) collected individual taxa of benthic macroinvertebrates and analyzed the taxa separately. Figures 5-1 through 5-9 present hazardous substance concentrations in either the composite benthic macroinvertebrate samples collected by the U.S. FWS and University of Wyoming or in *Hydropsyche* spp. collected by the USGS or Boggs. *Hydropsyche* are omnivorous caddisflies (Merritt and Cummins (eds.), 1984), and were the only taxonomic group consistently collected by the USGS and Boggs throughout the Clark Fork River between Warm Springs and Milltown and in the control streams, thus allowing for comparisons of hazardous substance concentrations between sampling stations. Included in the figures are the upper 95% confidence limit for the mean concentrations in control stream macroinvertebrates. Confidence limits for concentrations in *Hydropsyche* spp. (Figures 5-3, 5-5, 5-7, and 5-9) in controls were calculated by pooling USGS results from Rock Creek and the Blackfoot River from three years of data collection (1987, 1989, and 1993; data from USGS, 1992 and Lambing, 1994).

For data from the U.S. FWS and University of Wyoming (1992) study, differences between mean hazardous substances concentrations in Clark Fork River macroinvertebrates and in control stream macroinvertebrates were compared using two-sample randomization tests (Manly, 1991). All data were natural log-transformed prior to the test to achieve homogeneity of variances. The natural log-transformation produced homogenous variances ($p > 0.05$) in 16 of the 20 pair-wise comparisons.

The results of the comparison using the data from the U.S. FWS and University of Wyoming (1992) are presented in Table 5-2. As shown in Table 5-2, mean hazardous substance concentrations are significantly higher (using a one-tailed p-value) in Clark Fork River macroinvertebrates than in macroinvertebrates collected from control streams (except for arsenic in macroinvertebrates collected from Turah).

For the USGS studies (Cain et al., 1992; Lambing et al., 1994) and the study by Boggs (1994), available data were not considered sufficient for statistical analyses. However, as the data in Table 5-3 and Figures 5-3, 5-5, 5-7, and 5-9 show, mean concentrations of cadmium, copper, lead, and zinc are consistently higher in macroinvertebrates (*Hydropsyche* spp.) from throughout the Clark Fork River (Warm Springs Ponds to Milltown) than those from the control streams. Data collected by the same group of investigators from 1987-1992 also show consistently higher hazardous substance concentrations in Clark Fork River macroinvertebrates than in control stream macroinvertebrates (Hornberger and Luoma, 1994).

Table 5-2
Mean Metals Concentration in Benthic Macroinvertebrates Collected From the Clark Fork River Basin

Location		Mean Concentration (ppm dry weight)				
		As	Cd	Cu	Pb	Zn
Control (Rock Creek)		2.7	0.13	26	0.54	212
Clark Fork River	At Warm Springs (0 mi.)	14.6*	1.2*	122*	10.7*	304*
	At Deer Lodge (21.5 mi.)	13.1*	1.4*	181*	9.9*	293*
	At Gold Cr. Bridge (47.7 mi.)	26.8*	2.2*	266*	32.2*	453*
	At Turah (112.6 mi.)	3.4	1.8*	48*	3.8*	359*

* Statistically significant at p-value < 0.05 (vs. controls).

Source: U.S. FWS and University of Wyoming, 1992.

Table 5-3
Mean Metals Concentrations in *Hydropsyche* spp. Collected From the Clark Fork River

Location	Year Sampled	Number of Locations Sampled	Mean Concentration[1] (ppm dry weight)			
			Cd	Cu	Pb	Zn
Control (Rock Cr.; Blackfoot R.)	1986-90[2]	2	0.2	19	0.8	111
	1993[3]	2	0.2	16	1.0	154
Clark Fork River 0-60 miles[5]	1986[2]	4	3.4	140	11.2	254
	1991-2[4]	2	0.8	72	--	196
	1993[3]	3	2.3	102	6.4	262
Clark Fork River 60-120 miles[5]	1986[2]	4	2.1	65	6.6	226
	1991-2[4]	1	0.3	38	--	149
	1993[3]	2	1.1	30	5.8	207

1 Values are means of individual *Hydropsyche* or composites of individuals.
2 Source: USGS, 1992.
3 Source: Lambing, 1994.
4 Source: Boggs, 1994.
5 Clark Fork River 0-60 miles is from Warm Springs to Flint Cr.; 60-120 miles is from Flint Cr. to Milltown.

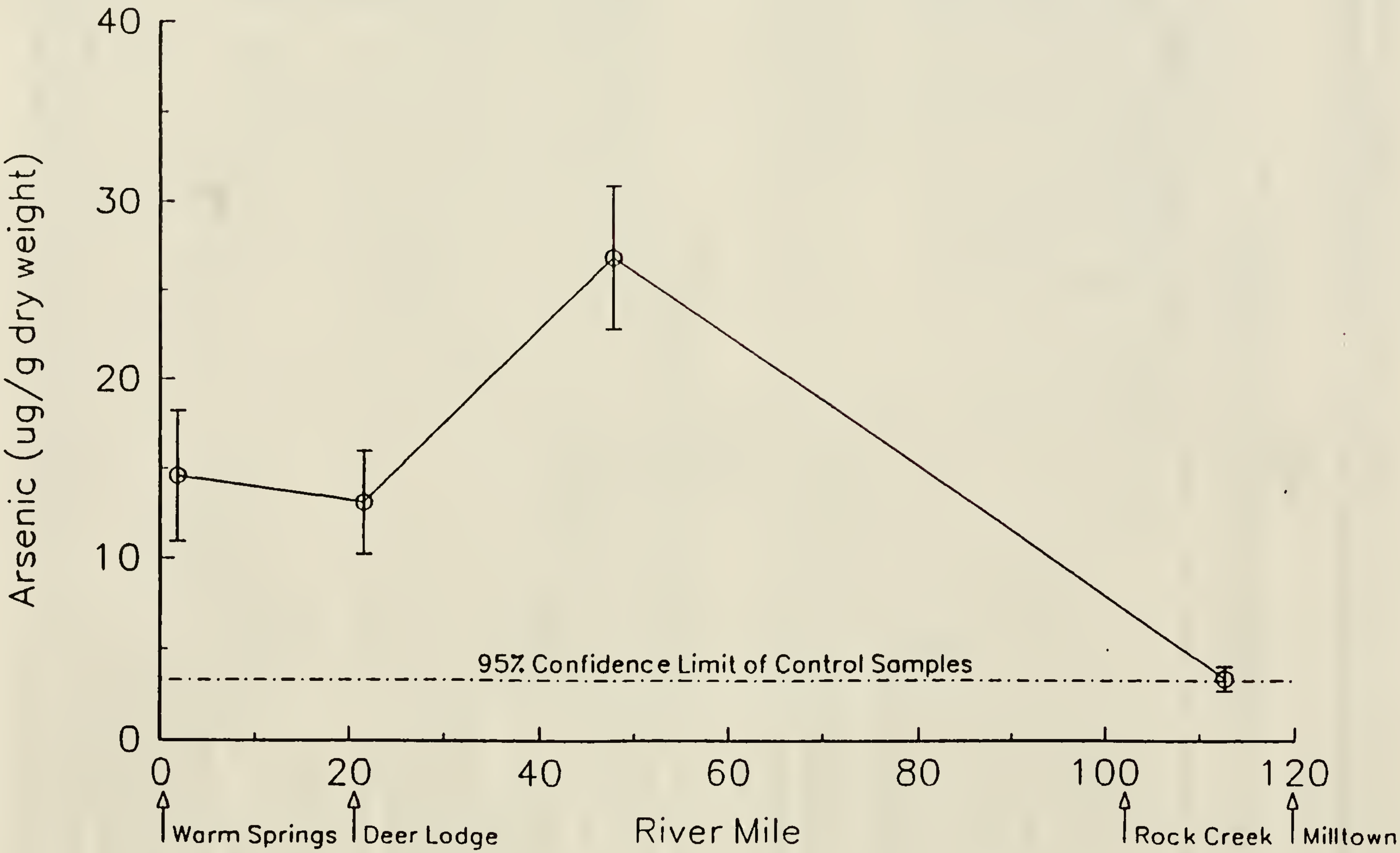

Figure 5-1. Arsenic in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

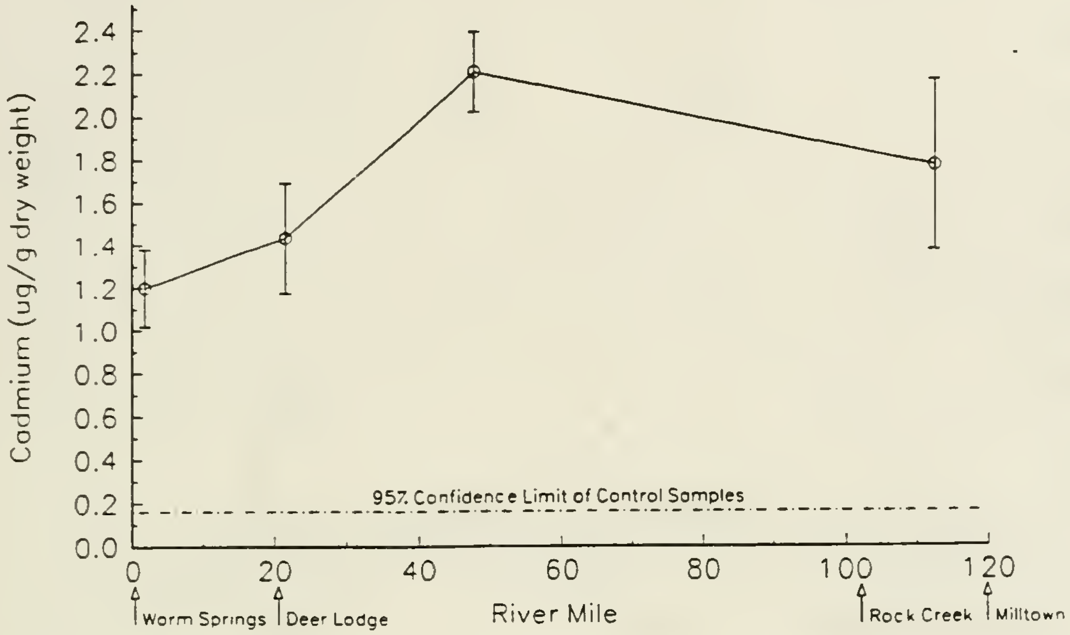

Figure 5-2. Cadmium in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

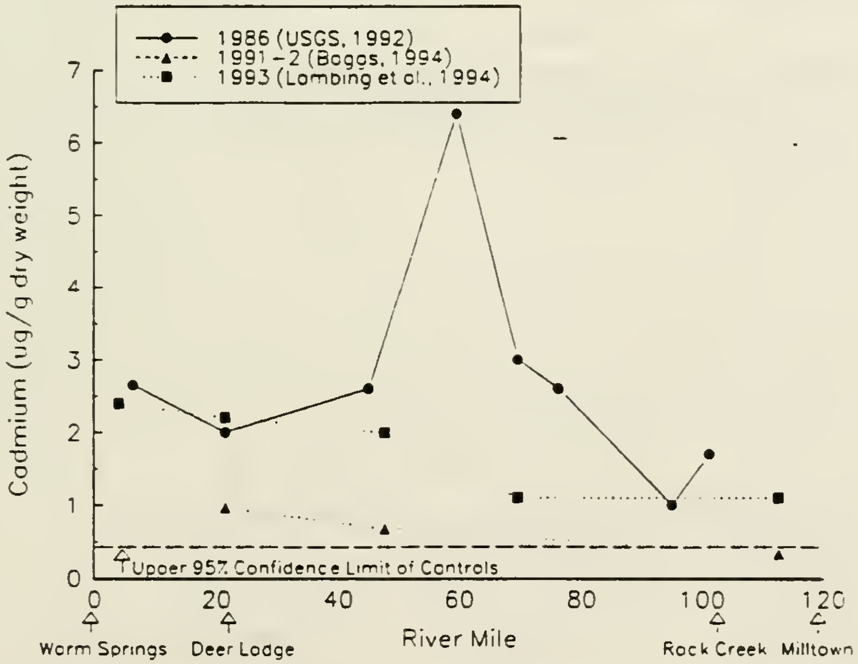

Figure 5-3. Cadmium in Field-Collected *Hydropsyche* spp. Invertebrates, Clark Fork River.

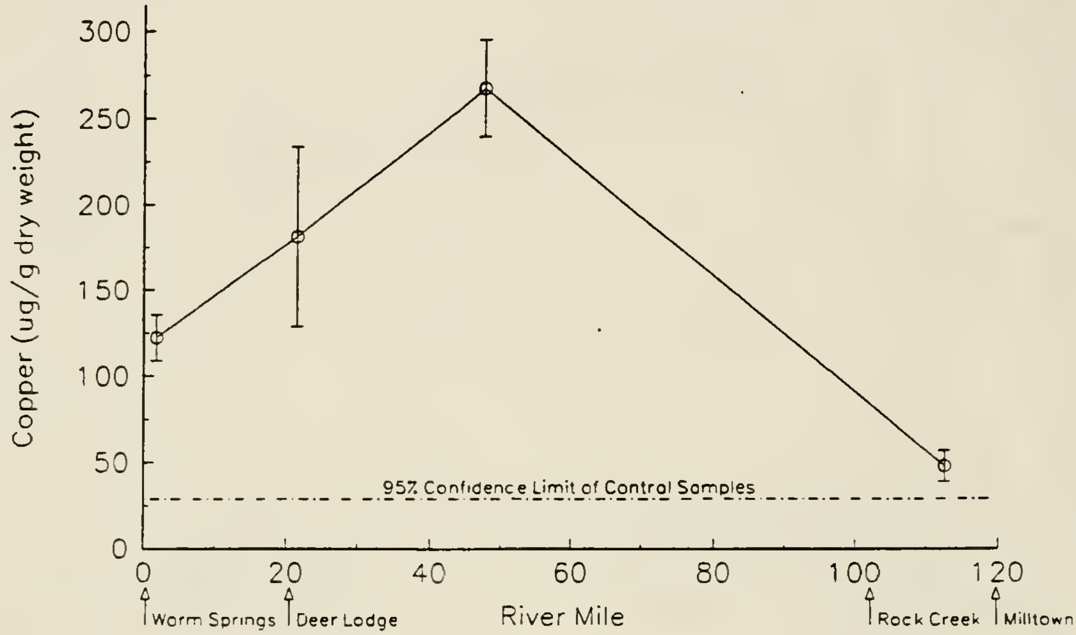

Figure 5-4. Copper in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

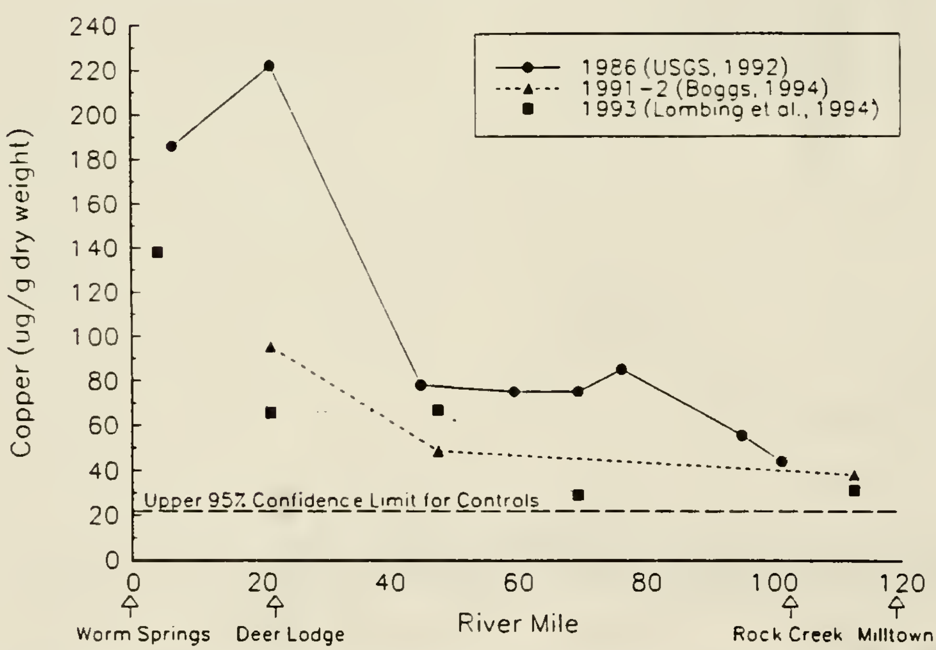

Figure 5-5. Copper in Field-Collected *Hydropsyche* spp. Invertebrates, Clark Fork River.

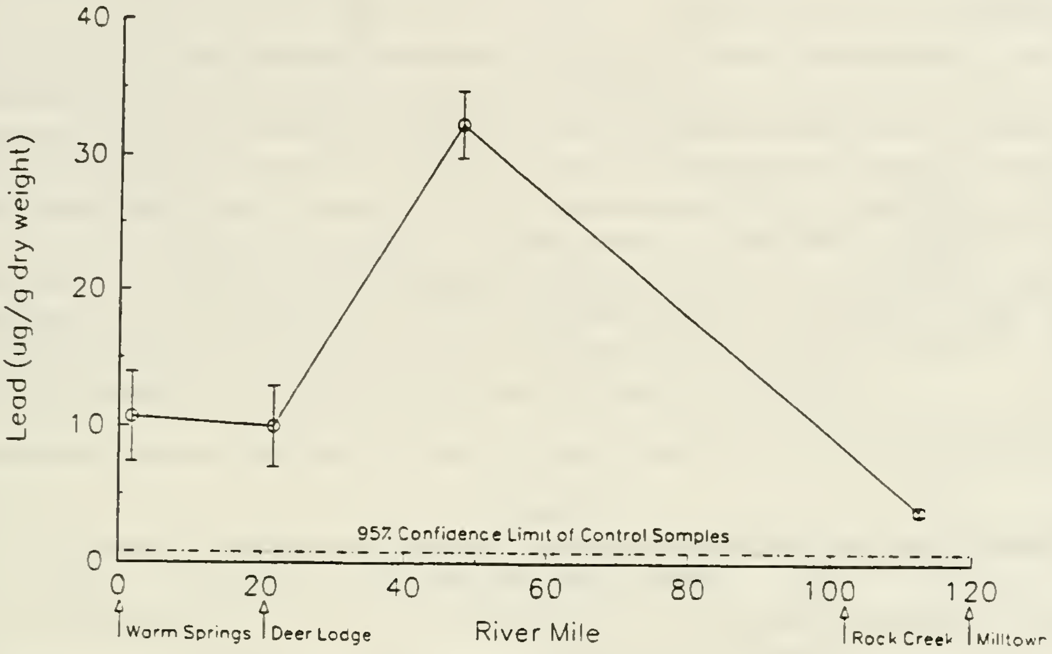

Figure 5-6. Lead in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

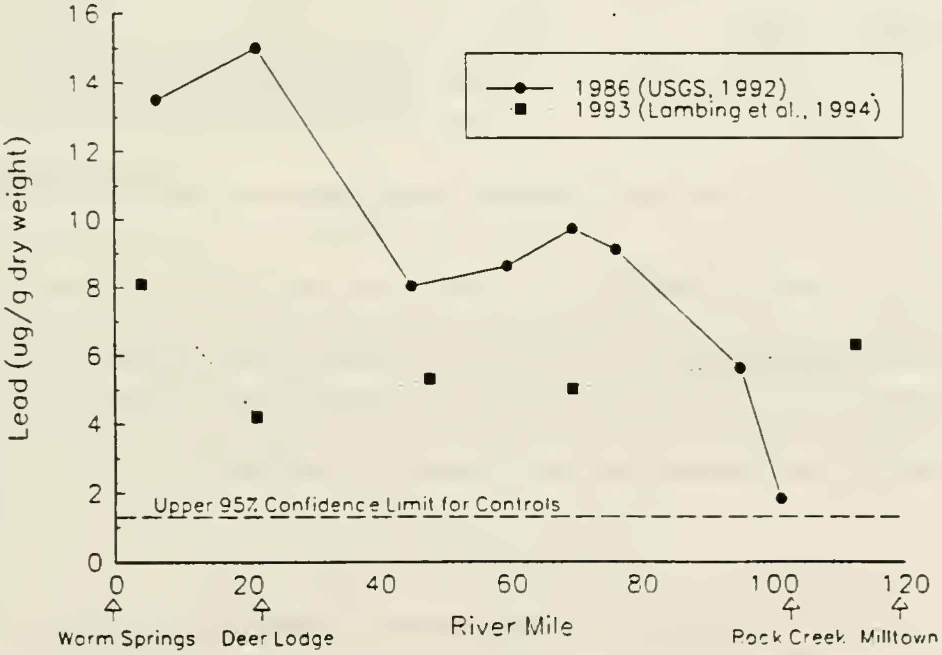

Figure 5-7. Lead in Field-Collected *Hydropsyche* spp. Invertebrates, Clark Fork River.

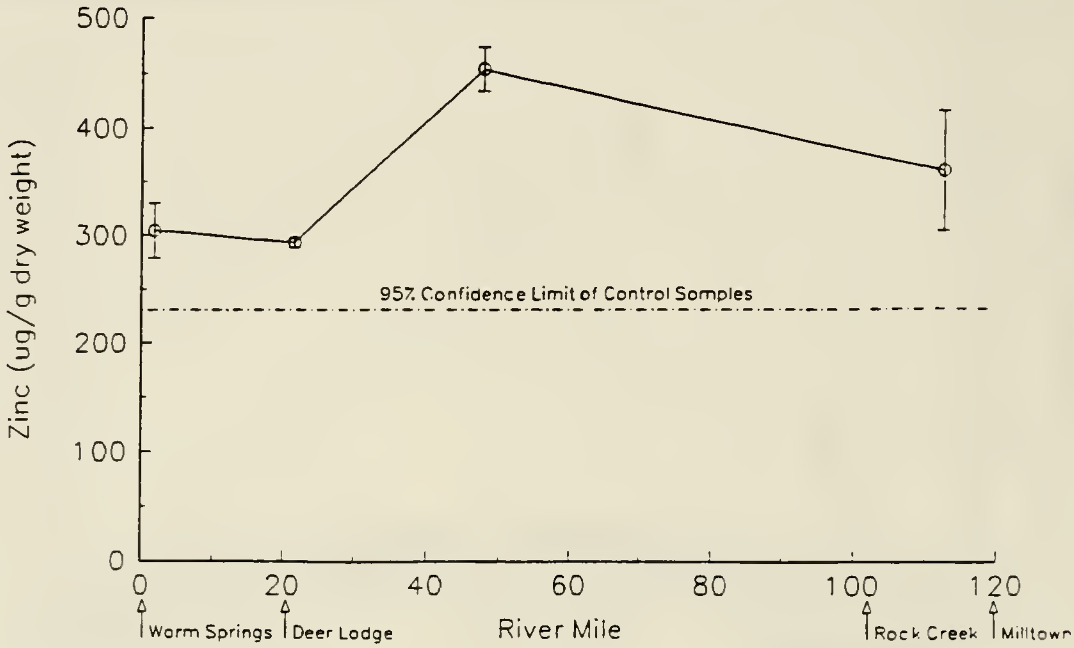

Figure 5-8. Zinc in Field-Collected Invertebrates, Clark Fork River. Points are data means, brackets represent 95% confidence intervals. Source: U.S. FWS and University of Wyoming, 1992.

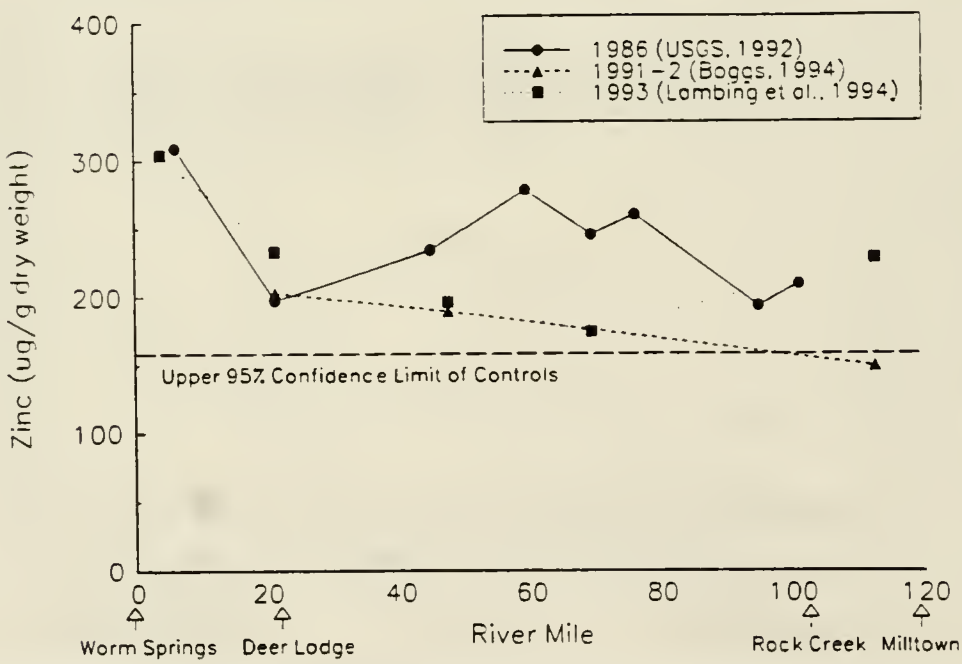

Figure 5-9. Zinc in Field-Collected *Hydropsyche* spp. Invertebrates, Clark Fork River.

Cain et al. (1992) used their 1986 data to conduct a correlation analysis between metals concentrations in field-collected macroinvertebrates and metals concentrations in sediments at the collection location. Table 5-4 presents the results. For the taxa *Hydropsyche* spp. and *Isogenoides* spp., which Cain et al. (1992) found throughout the length of the Clark Fork River between Warm Springs Ponds and Milltown, concentrations of copper and cadmium in tissues were significantly correlated with sediment concentrations. Concentrations of lead and zinc were also significantly correlated in *Hydropsyche* spp., but not in *Isogenoides* spp. Variations are expected due to the complex interaction of sediment geochemical and biological factors (Axtmann et al., 1990; Timmermans, 1993). Overall, the strong correlations indicate that hazardous substance uptake and accumulation in Clark Fork River macroinvertebrates is associated with elevated sediment concentrations.

Table 5-4
Correlation of Whole-Body Invertebrate Concentrations and Bed Sediment Concentrations (data collected in 1986)

	Correlation Coefficient (r)			
Taxon	**Copper**	**Cadmium**	**Lead**	**Zinc**
Hydropsyche spp. (n = 13)	0.86*	0.71*	0.74*	0.74*
Isogenoides spp. (n = 12)	0.74*	0.66*	0.36 (n = 11)	0.25

* Statistically significant at $p < 0.05$.

Source: Cain et al., 1992.

Mean concentrations in the amphipod *Hyalella azteca* exposed to Clark Fork River and control sediments in a 28-day laboratory test are presented in Table 5-5 and in Figures 5-10 through 5-14. Statistical comparisons were not made between individual Clark Fork River stations and the control station because of the small sample size (n = 2 for each sample location). These data indicate that exposure to contaminated Clark Fork River sediments causes accumulation of hazardous substances in macroinvertebrates under controlled laboratory conditions.

5.2.3 <u>Pathway Analysis: Metals Concentrations in Periphyton</u>

In addition to sediments, a potential pathway of hazardous substance transport to benthic macroinvertebrates is periphyton. Periphyton is plant material that grows on submerged

Table 5-5
Mean Concentrations of Hazardous Substances in *Hyalella azteca* Exposed to Clark Fork River and Control Sediments
(n = 2 composite samples)

		Metals Concentrations in *H. azteca* (ppm dry weight)				
		Arsenic	**Cadmium**	**Copper**	**Lead**	**Zinc**
Sediment from the Clark Fork River	At Warm Springs	12.2	0.3	87	7.2	106
	At Deer Lodge	3.8	1.0	124	5.8	80
	At Gold Creek Bridge	1.9	0.4	127	2.0	79
	At Turah	1.1	0.53	124	5.8	74
Sediment from control areas		0.43	0.14	84	0.4	56
Source: U.S. FWS and University of Wyoming, 1992.						

surfaces, and is an important food source and habitat for many benthic macroinvertebrates. Periphyton accumulates metals in contaminated stream systems, in both the biotic and abiotic components (Johnson et al., 1978; Newman et al., 1985; Kelly 1988; Newman and McIntosh, 1989; Boston et al., 1991; Stewart et al., 1993). Concentrations of heavy metals in periphyton have been employed as indicators of the presence of heavy metals in natural streams (Foster, 1982; Kelly, 1988; Kiffney and Clements, 1993) and in stream microcosms (Kaufman, 1982;

Selby et al., 1985; Genter et al., 1987). Periphyton communities are often the major primary producers in streams and therefore represent an important link in the transfer of contaminants to higher trophic levels (Kiffney and Clements, 1993; Stewart et al., 1993). Many benthic macroinvertebrates ("grazers") rely on it as their principal food source and/or their primary habitat.

Periphyton was collected in the summer of 1994 from riffle substrates in the Clark Fork River between Warm Springs Ponds and Milltown and from control streams. Periphyton was analyzed for the hazardous substances cadmium, copper, lead, and zinc. Details of the sampling and analysis are contained in Appendix A. The samples collected and analyzed included periphyton, benthic macroinvertebrates in the periphyton, and particulate abiotic material carried by the river that becomes imbedded in the periphyton. Samples were collected from three control areas: Rock Creek, Little Blackfoot River (both tributaries to the Clark Fork River) and the Big Hole River (also used as a control area for fisheries injury quantification - see Chapter 6.0).

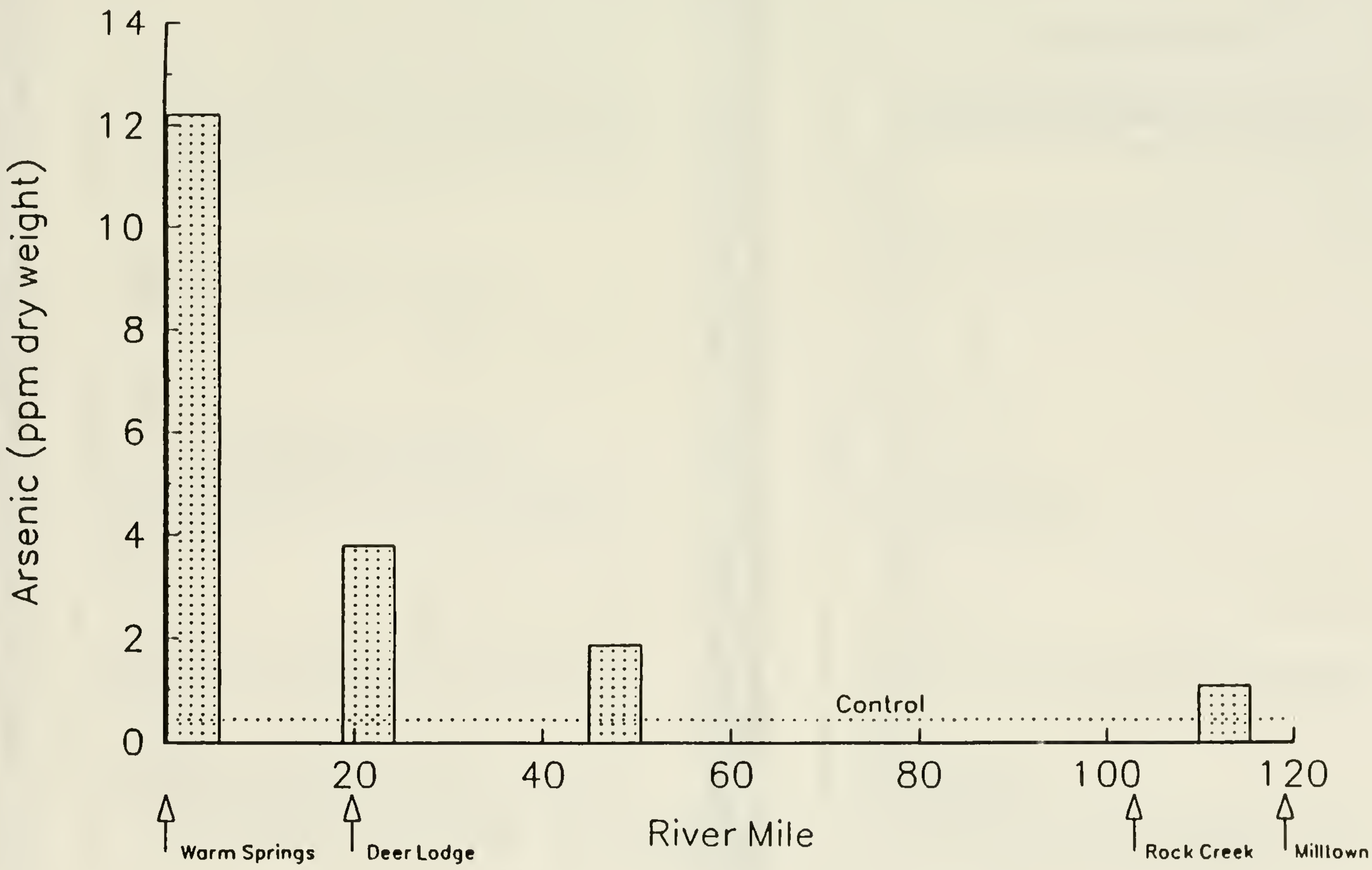

Figure 5-10. Mean Arsenic in Amphipods Exposed to Sediments from Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

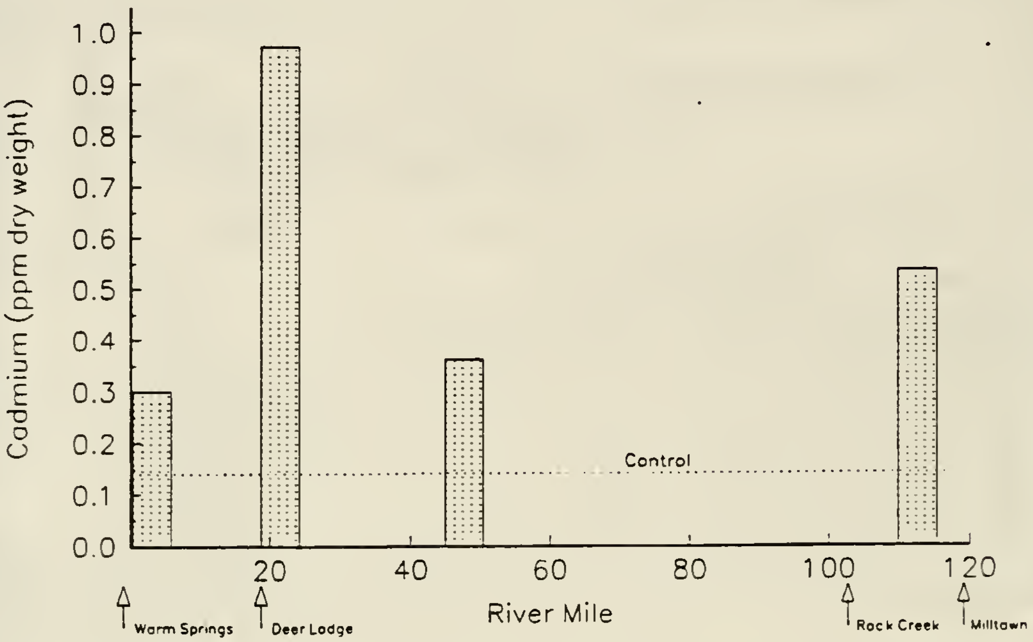

Figure 5-11. Mean Cadmium in Amphipods Exposed to Sediments from Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

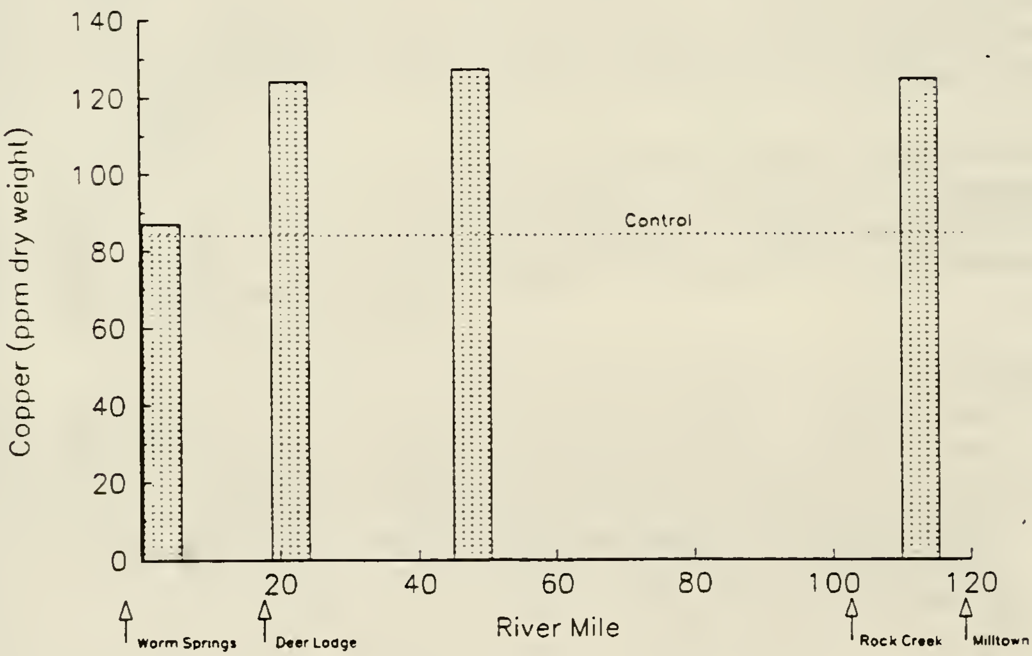

Figure 5-12. Mean Copper in Amphipods Exposed to Sediments from Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

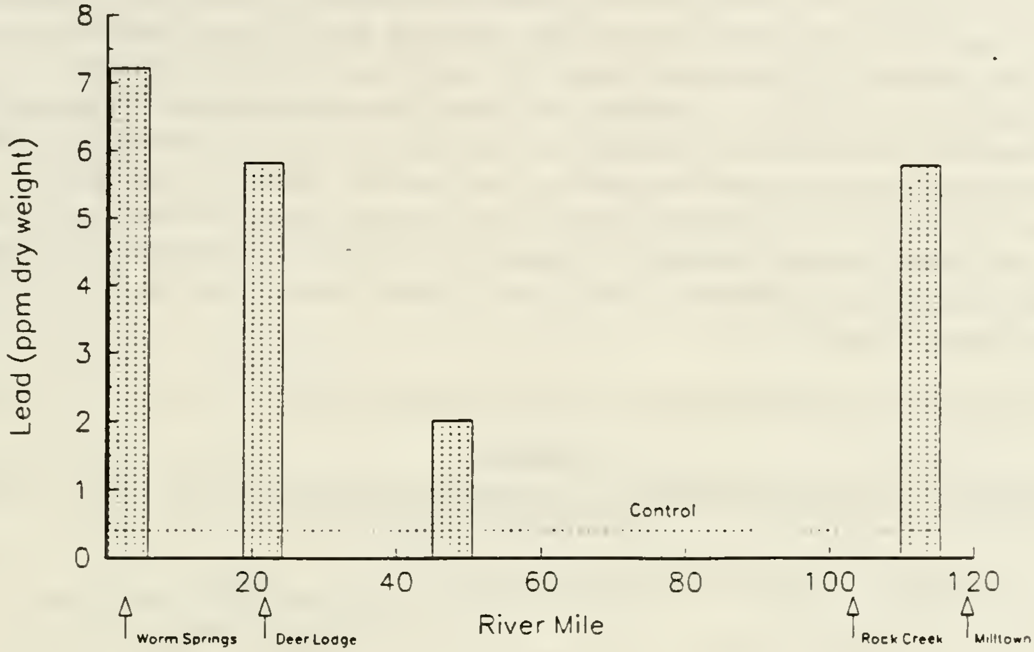

Figure 5-13. Mean Lead in Amphipods Exposed to Sediments from Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

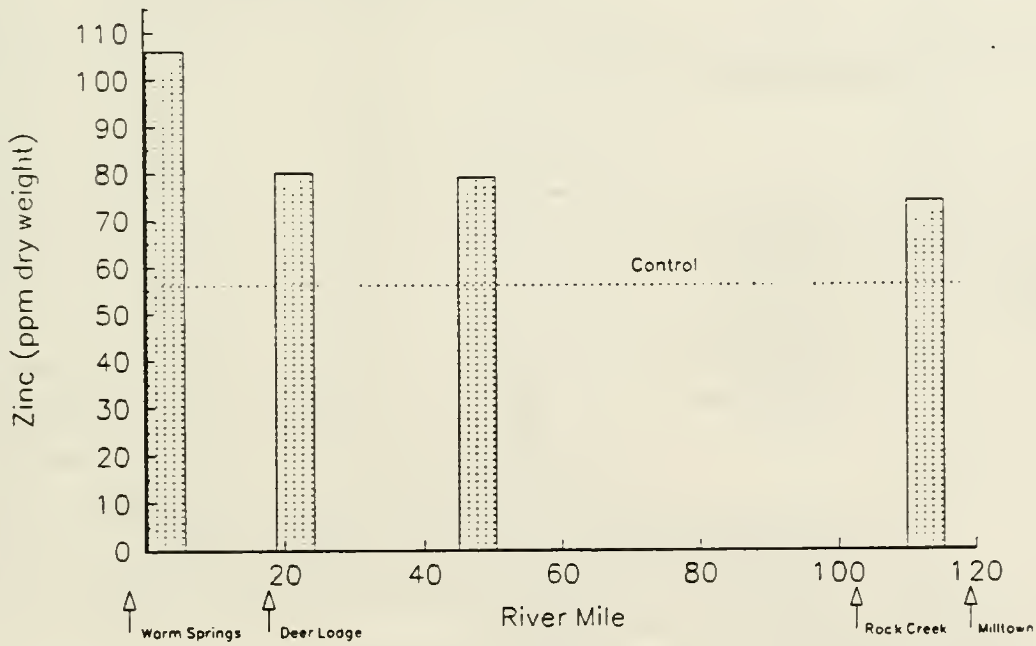

Figure 5-14. Mean Zinc in Amphipods Exposed to Sediments from Clark Fork River and Control Streams. Source: U.S. FWS and University of Wyoming, 1992.

Table 5-6 and Figures 5-15 through 5-18 present concentrations of cadmium, copper, lead, and zinc measured in periphyton collected from the Clark Fork River and control areas. Figures 5-15 through 5-18 include the upper 95% confidence limit for periphyton concentrations in control areas. The table and figures show that periphyton throughout the Clark Fork River between Warm Springs Ponds and Milltown contain elevated concentrations of the hazardous substances cadmium, copper, lead, and zinc relative to control areas. Hazardous substance concentrations are highest in periphyton collected from near Warm Springs, and show a general decrease with downstream distance to Milltown. The pattern of hazardous substance concentrations in periphyton is similar to that observed for Clark Fork River sediments (Chapter 3.0).

Table 5-6
Concentrations of Hazardous Substances in Periphyton Collected from the Clark Fork River and Control Areas

	Site	Hazardous Substance Concentration (mg/kg dry weight)			
		Cadmium	Copper	Lead	Zinc
Control	Big Hole R.[1]	< 1.0	< 9.6	< 9.6	41.0
		< 1.0	< 10.5	< 10.5	35.0
		< 0.93	< 9.3	< 9.3	50.0
	Little Blackfoot R.[1]	< 1.0	33.0	< 10.4	106
		< 1.0	27.0	< 10.1	101
		< 1.1	27.1	< 10.6	99.4
	Rock Creek	< 1.0	< 10.0	< 10.0	20.2
Clark Fork River	At Warm Springs	7.4	734	46.0	1,500
	At Galen	6.4	325	31.0	918
	At Deer Lodge[2]	3.0	242	34.9	554
	At Gold Creek[1]	2.6	126	17.8	398
		2.0	128	15.2	356
		2.4	110	17.7	422
	At Bearmouth	1.4	110	21.9	359
	At Turah	1.0	65.1	11.7	287

1 Data for three field replicates are shown.
2 Data shown are the means of three laboratory replicates.

Source: MDOJ, 1994.

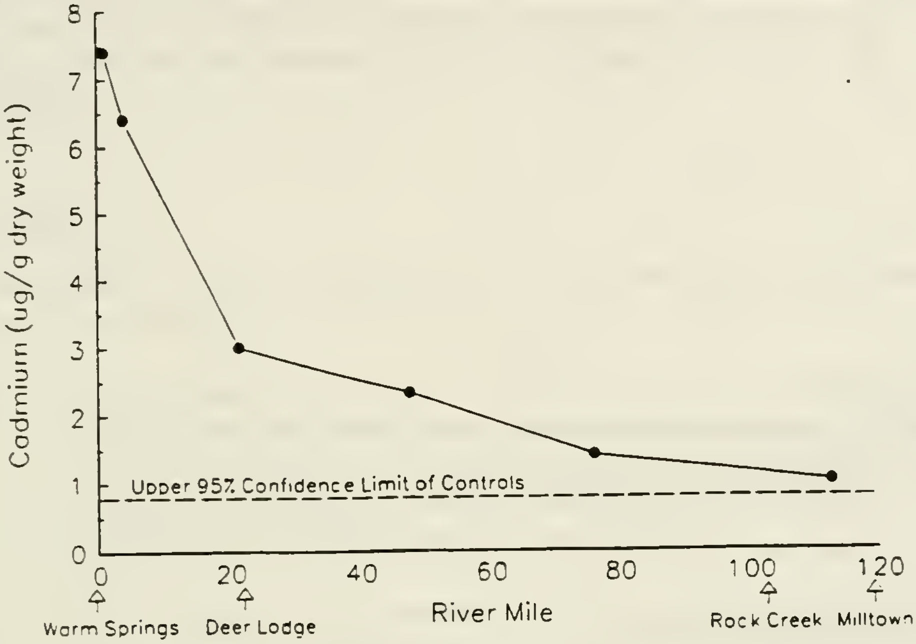

Figure 5-15. Cadmium Concentrations in Periphyton Collected from the Clark Fork River. Where field or laboratory replicates were analyzed (Table 5-6), data shown are means of the replicates.

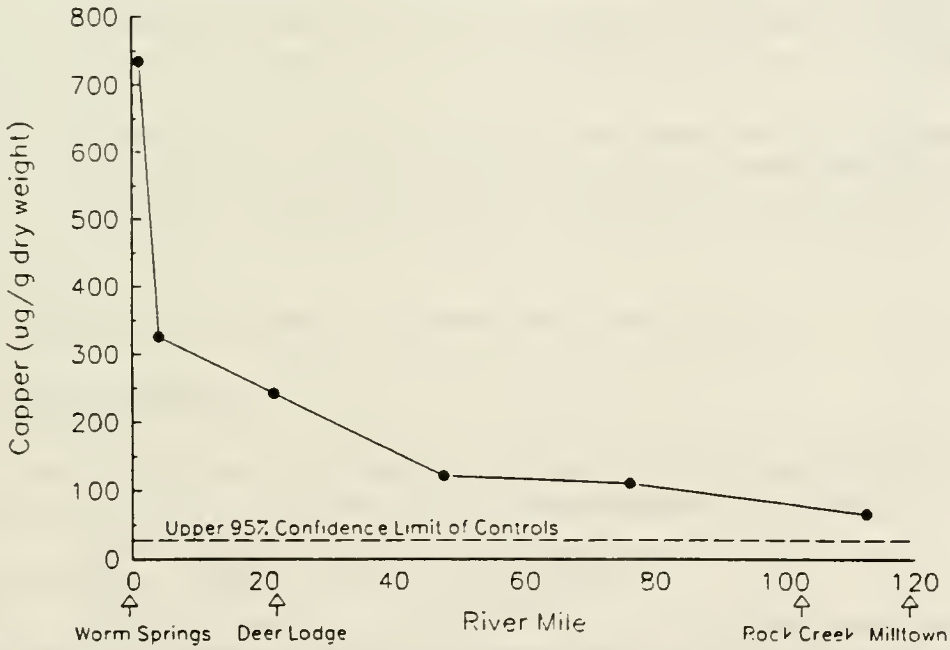

Figure 5-16. Copper Concentrations in Periphyton Collected from the Clark Fork River. Where field or laboratory replicates were analyzed (Table 5-6), data shown are means of the replicates.

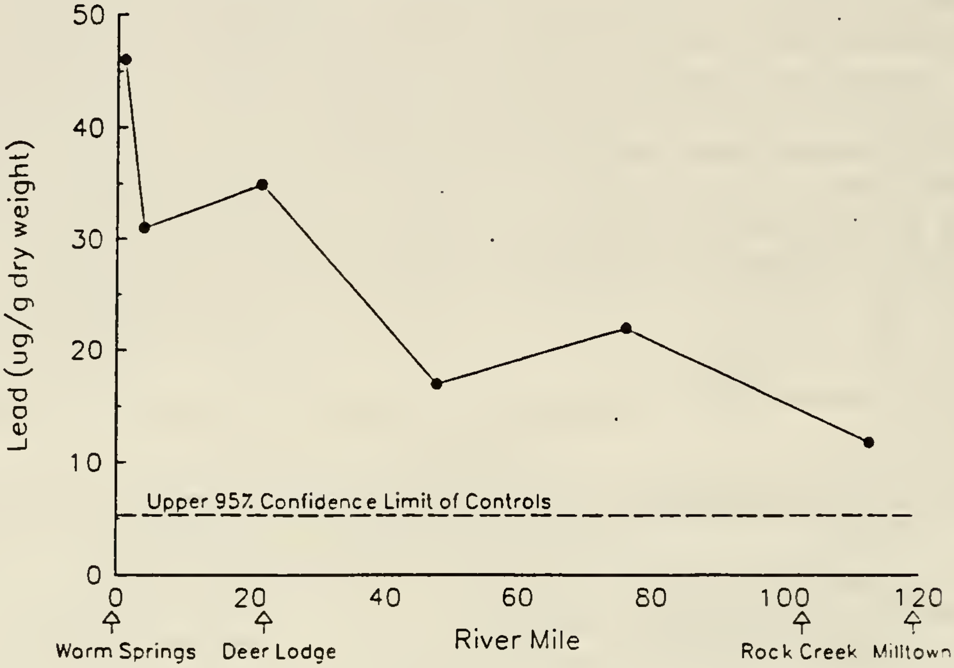

Figure 5-17. Lead Concentrations in Periphyton Collected from the Clark Fork River. Where field or laboratory replicates were analyzed (Table 5-6), data shown are means of the replicates.

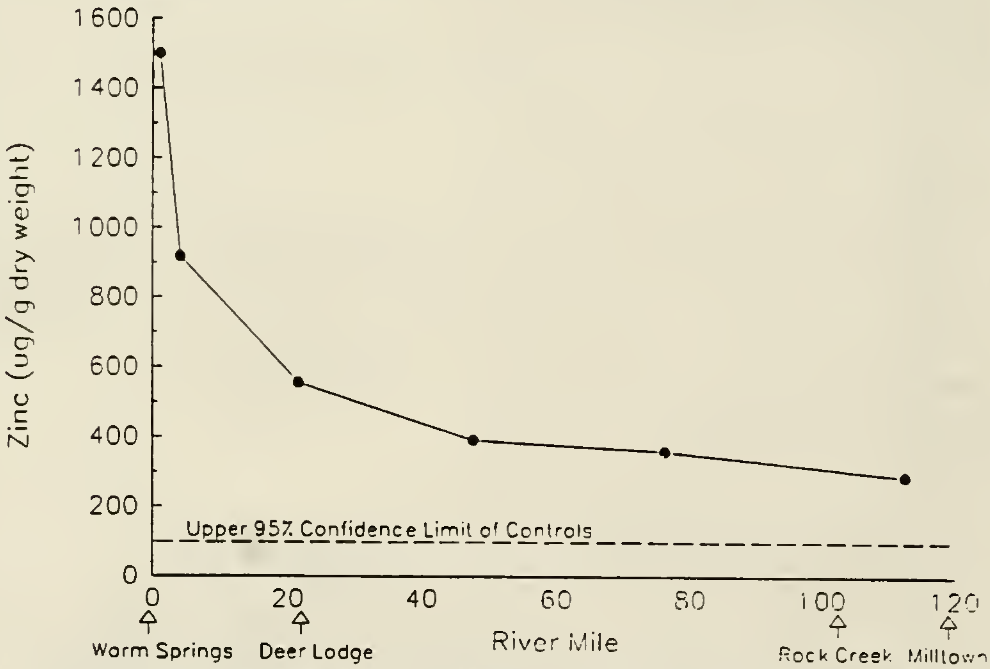

Figure 5-18. Zinc Concentrations in Periphyton Collected from the Clark Fork River. Where field or laboratory replicates were analyzed (Table 5-6), data shown are means of the replicates.

In summary, Clark Fork River periphyton have accumulated hazardous substances at concentrations orders of magnitude greater than periphyton in control streams. Periphyton can thus act as an exposure pathway for benthic macroinvertebrates which feed on or live in the periphyton.

5.2.4 Conclusions

Several important conclusions can be drawn from the investigations of bioaccumulation in benthic macroinvertebrates:

- Benthic macroinvertebrates from Silver Bow Creek and the Clark Fork River have accumulated hazardous substances at concentrations significantly greater than those from control areas. Because of this accumulation, benthic macroinvertebrates are a critical pathway by which fish are exposed to, and injured by, hazardous substances (see Chapter 6.0)

- Benthic macroinvertebrates exposed to Silver Bow Creek and Clark Fork River sediments in a controlled laboratory environment accumulate hazardous substances at concentrations well above those in organisms exposed to control area sediments.

- The concentration of hazardous substances accumulated in benthic macroinvertebrates in Silver Bow Creek and the Clark Fork River correlates with the concentration in the sediments to which they are exposed.

- Periphyton in the Clark Fork River accumulate hazardous substances at concentrations above those observed in control streams and thus can act as a pathway of hazardous substances to benthic macroinvertebrates.

5.3 INJURY TO BENTHIC MACROINVERTEBRATES

5.3.1 Injury Definition

Benthic macroinvertebrates are a biological resource. The following definition of injury applies to benthic macroinvertebrates in Silver Bow Creek:

Category of Injury: Death [43 CFR § 11.62 (f)(4)(i)]

- A statistically significant difference can be measured in the total mortality and/or mortality rates between population samples of test organisms placed in

exposure chambers containing concentrations of hazardous substances and those in a control chamber. [43 CFR § 11.62 (f)(4)(i)(E).]

Section 5.3.2 presents the results of controlled laboratory studies that document the toxicity of Silver Bow Creek sediments to standard macroinvertebrate test species. In Section 5.3.3, this observed toxicity to benthic macroinvertebrates is shown to corroborate with field observations of injured benthic macroinvertebrate communities in Silver Bow Creek.

5.3.2 Laboratory Toxicity Tests

This section describes the results of laboratory toxicity tests using benthic macroinvertebrates. Laboratory toxicity tests using benthic species and sediment chemistry analyses have been used in conjunction with field studies of community structure to corroborate the determination of injury to the benthic community (Chapman et al., 1992). The use of, methods for, and interpretation of sediment toxicity testing using benthic species are fully documented in the scientific literature (e.g., Burton, 1991; Burton, 1992).

In 1991, the U.S. FWS and University of Wyoming collected sediment from Silver Bow Creek one kilometer (0.6 miles) above Warm Springs Ponds (U.S. FWS and University of Wyoming, 1992).[1] Control sediment was collected from Rock Creek. These sediments were used in a series of controlled laboratory toxicity tests, including a 28-day whole-sediment test using the amphipod *Hyalella azteca*, a 14-day whole-sediment test using the midge *Chironomus riparius*, and sediment porewater tests using *Daphnia magna* (48-hour exposure), and the Microtox bioassay (15 minute exposure) (Tables 5-7 and 5-8).[2] In the whole-sediment tests using *Hyalella azteca* and *Chironomus riparius*, measured endpoints were survival, growth, and percent sexual maturation (*Hyalella azteca* only). In the porewater tests, the measured endpoint was survival of *Daphnia magna*. In the Microtox bioassay, the endpoint was luminescence (a measure of biological function). Results for porewater tests are expressed as an EC50 concentration, which is the concentration of the porewater sample (expressed as a percent) which kills 50% of the test organisms (or reduces bioluminescence by 50%, in the case of Microtox). For example, the EC50 value of 17% for *Daphnia magna* means that when *Daphnia magna* are exposed to a mixture of 17% Silver Bow Creek porewater and 83% clean laboratory water, 50% of the organisms die within 48 hours. Overall, the results of the tests showed that Silver Bow Creek sediments were toxic to macroinvertebrates, whereas Rock Creek sediments were not.

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[1] This study was also discussed in Section 5.2.1.

[2] A whole sediment test is a test in which organisms are exposed directly to the sediments, while in a porewater test organisms are exposed to water "squeezed" from the wet sediments. The Microtox test is a rapid laboratory procedure that is used to assess toxicity to aquatic biota.

Table 5-7
Sediment Toxicity Test Results Using Sediment Porewater
Values are EC50s (95% confidence intervals in parentheses) Expressed as a Percentage of the Sample Which Results in 50% Mortality (*Daphnia*) or 50% Reduction in Luminescence (Microtox)

	Control (Rock Creek)	Silver Bow Creek
Daphnia magna (48 hour)	> 100*	17 (10-26)
Microtox	> 100*	19 (18-20)

* > 100% EC50 means that 100% sample water caused less than 50% mortality (*Daphnia*) or 50% reduction in luminescence (Microtox).

Source: U.S. FWS and University of Wyoming, 1992.

Table 5-8
Whole-Sediment Toxicity Test Results
(values are means, standard error of the mean in parentheses)

Species	Measured Endpoint	Control Sediments (Rock Creek)	Silver Bow Creek Sediments
Hyalella azteca	% survival	89 (3.8)	48 (9.7)*
H. azteca	length (mm)	4.01 (0.22)	2.85 (0.25)*
H. azteca	% sexually mature males	28 (2.2)	8 (5.0)*
Chironomus riparius	% survival	87 (2.4)	77 (7.2)
C. riparius	length (mm)	13.3 (0.17)	16.0 (0.20)*
Daphnia magna	% survival	100	100

* Statistically different from controls ($p < 0.05$).

Source: U.S. FWS and University of Wyoming, 1992.

Whole-sediment test results were compared statistically to determine significant differences between responses to Silver Bow Creek sediments and control sediments. The results show that Silver Bow Creek sediments caused statistically significant adverse changes to *Hyalella azteca* survival, growth, and sexual maturation in whole-sediment tests and *Daphnia magna* survival and Microtox bioluminescence in porewater tests, relative to control sediments (Table 5-8).

No toxicity was observed in 14-day whole-sediment tests using *Chironomus riparius*, but this organism is known to be less sensitive to metals toxicity than *Hyalella azteca* (Ingersoll and Nelson, 1990 and Nelson et al., 1992, as cited in U.S. FWS and University of Wyoming, 1992). Analyses of porewater and sediment chemistry showed that observed toxicity in Silver Bow Creek sediments was strongly associated with elevated concentrations of metals in sediments, sediment porewater, and overlying water (U.S. FWS and University of Wyoming, 1992).

5.3.3 Benthic Community Structure

Measuring changes in community structure is a commonly-used method of assessing impacts of metals on benthic macroinvertebrates. One of the first studies on the effects of metals on benthic macroinvertebrate community structure was conducted by Carpenter (1924) who reported reduced number of taxa and an "impoverishment of the fauna" at sites downstream from mining operations. Since that time, many laboratory and field studies have documented metal impacts on benthic macroinvertebrate community structure (for reviews see Ford, 1989; Clements, 1991; Luoma and Carter, 1991; LaPoint and Fairchild, 1992).

A reduction in the number of taxa present is one of the most consistent and sensitive indicators of metals impacts to benthic macroinvertebrate communities (Clements, 1991; Luoma and Carter, 1991). Taxa reductions caused by metals have been documented in artificial laboratory streams (Selby et al., 1985; Clements et al., 1988; Clements et al., 1989; Clements et al., 1992; Kiffney and Clements, 1994), natural streams experimentally dosed with metals (Winner et al., 1975, as cited in Clements, 1991; Winner et al., 1980; Leland, 1985; as cited in Clements, 1991; Leland et al., 1989), and in streams or rivers receiving metal pollution (for a review, see Clements, 1991).

Another measure of metals impacts on benthic macroinvertebrate communities is reduced abundance of species or taxonomic groups that are sensitive to metals contamination. Many organisms in the order Ephemeroptera (mayflies) are sensitive to metals contamination, and a reduction in the abundance of mayflies due to metals contamination has been well documented in many stream ecosystems (Winner et al., 1980; Ramusino et al., 1981; Specht et al., 1984; Van Hassel and Gaulke, 1986; Clements, 1991; Clements et al., 1992; Kiffney and Clements, 1994). Clements (1994) concluded that decreased abundance of mayflies is one of the most reliable indicators of heavy metal pollution in stream ecosystems. A decrease

in mayfly abundance has also been documented in experimental streams dosed with copper (Clements et al., 1988; Clements et al., 1989; Leland et al., 1989; Clements et al., 1992).

Therefore, a reduction in the number of taxa and in the density of Ephemeropterans are reliable means of determining injuries to benthic macroinvertebrates. Both measures meet the four acceptance criteria for determining injuries to biological resources [43 CFR § 11.62 (f)(2)].

Silver Bow Creek Field Investigations

At least three investigations of benthic communities in Silver Bow Creek have been conducted in recent years: Chadwick et al. (1986) collected samples in 1984; EA Engineering (1991) collected samples in 1988 and 1989; and MDHES (1991) and McGuire (1993; 1994) collected samples from 1986 through 1993. Table 5-9 summarizes the dates, number of stations in Silver Bow Creek, and control streams used in the three studies.

Table 5-9
Summary of Benthic Community Studies on Silver Bow Creek

Source	Dates of Sampling	Number of Stations in Silver Bow Creek	Control Stream
Chadwick, 1985	1984	5	Mill-Willow Bypass
EA Engineering, 1991	1988-89	5 (same locations as above)	Mill-Willow Bypass
MDHES, 1991; McGuire, 1993; McGuire, 1994	1986-93	4 (two same as above)	Mill-Willow Bypass

Both the number of taxa (Figure 5-19) and Ephemeropteran density (Figure 5-20) are greatly reduced in Silver Bow Creek relative to the control stream. Note that Figure 5-20 is plotted using a logarithmic scale on the y-axis.

Differences in observed number of taxa and Ephemeropteran density in Silver Bow Creek and the control stream were compared using two-sample randomization tests (Manly, 1991). Since the number of taxa and Ephemeropteran density is relatively constant with downstream distance within Silver Bow Creek and between studies (see Figures 5-19 and 5-20), all Silver Bow Creek stations from all three studies were pooled. Similarly, results from the control stream in the three studies were also pooled. Both the number of taxa and Ephemeropteran density were natural log-transformed prior to the two-sample randomization test to give variances within the two groups that were homogeneous ($p > 0.05$).

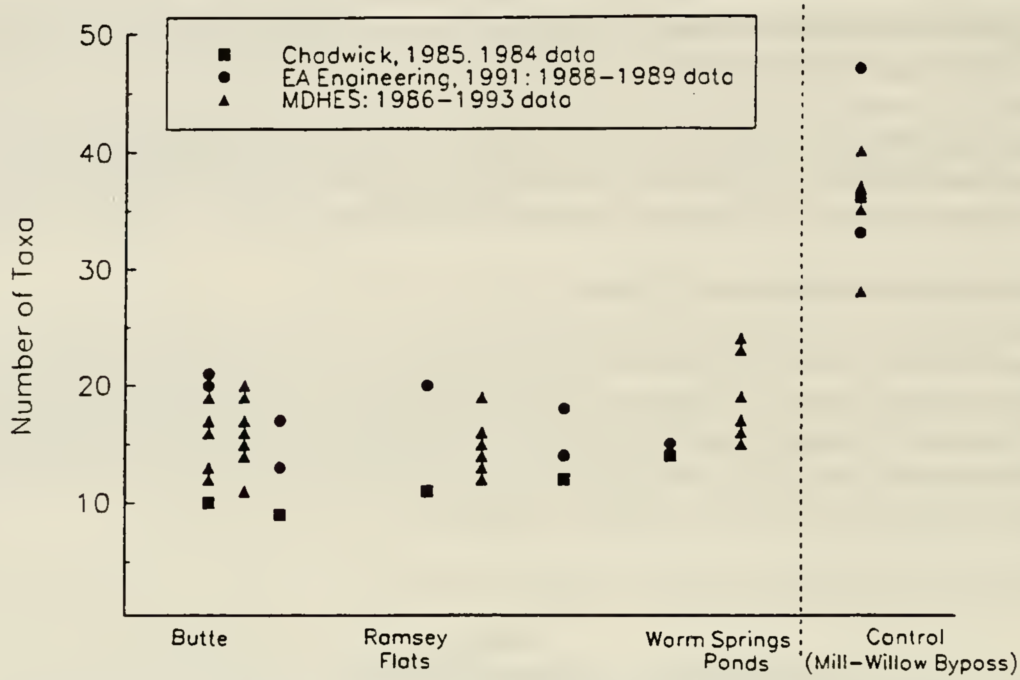

Figure 5-19. Number of Taxa vs. Silver Bow Creek Distance. Silver Bow Creek sampling stations are ordered from left to right by decreasing distance from Butte. The control is included on the far right of the figure.

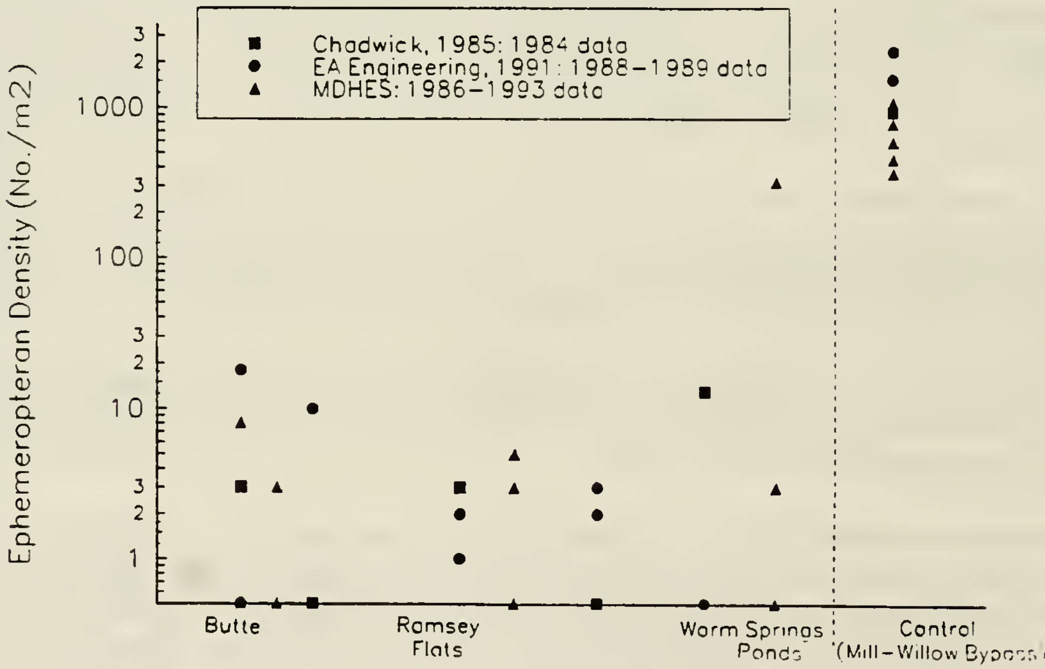

Figure 5-20. Ephemeropteran Density vs. Silver Bow Creek Distance. Note logarithmic scale. Silver Bow Creek sampling stations are ordered from left to right by decreasing distance from Butte. The control is included on the far right of the figure.

Table 5-10 presents the results of the comparisons in number of taxa and Ephemeropteran density between Silver Bow Creek and controls. The table shows that both the number of taxa and Ephemeropteran density are statistically significantly lower in Silver Bow Creek than in the control stream.

Table 5-10
Number of Taxa and Ephemeropteran Density in Silver Bow Creek vs. Control Streams[1]

	Number of Samples (pooled over years and locations)	Mean Number of Taxa	Mean Ephemeropteran Density (no./m^2)
Silver Bow Creek	45	15.6*	9*
Control	8	36.5	1010

[1] See Table 5-9 for data sources.
* Statistically different from control ($p < 0.05$).

As described in Chapter 3.0, bed sediments of Silver Bow Creek contain hazardous substances at concentrations above which major effects to benthic communities are expected. Exceedence of the threshold concentrations established by NOAA and the Province of Ontario for any single metal indicates that benthic communities are expected to be severely impacted; in Silver Bow Creek, arsenic, cadmium, copper, nickel, and zinc all exceed the thresholds.

Furthermore, Chadwick et al. (1986) determined that the observed severe impacts to the benthic community in Silver Bow Creek are not due to lack of suitable habitat. These field observations confirm that benthic macroinvertebrates have been injured throughout the entire length of Silver Bow Creek.

In conclusion:

- Laboratory toxicity tests confirm that exposure to Silver Bow Creek sediments (which have been shown to contain extremely elevated concentrations of hazardous substances) caused both mortality and reduced growth in macroinvertebrate test species.

- Field studies demonstrate that in Silver Bow Creek, the total number of benthic macroinvertebrate taxa and the density of Ephemeropterans (invertebrates known to be sensitive to hazardous substances) are greatly reduced relative to control streams. These reductions occur throughout the length of Silver Bow Creek.

- Silver Bow Creek sediment concentrations of arsenic, cadmium, copper, lead, and zinc all exceed threshold concentrations established by NOAA and the Province of Ontario for predicting when severe impacts to the benthic community can be expected.

5.4 INJURY QUANTIFICATION: SPATIAL AND TEMPORAL EXTENT OF INJURY

As described above, benthic macroinvertebrates presently are injured throughout the length of Silver Bow Creek. Previous investigations have shown that historically, macroinvertebrate populations have been injured to an even greater extent. The earliest available surveys of macroinvertebrates in Silver Bow Creek from the late 1950s found no benthic macroinvertebrates or only one pollution-tolerant species in the creek (Averett, 1961; Spindler, 1959). Additional investigations in the early 1970s also were unable to locate any macroinvertebrates in Silver Bow Creek (Chadwick & Associates, 1985). It is likely that Silver Bow Creek did not support any macroinvertebrates for decades before the first surveys in the 1950s, as well as during the period between the surveys of the 1950s and early 1970s; no water quality improvement measures were in place during these times that would have reduced contamination in Silver Bow Creek.

The benthic community of Silver Bow Creek did not begin to recover immediately after improvement in wastewater treatment that reduced metals loadings at the Weed Concentrator in 1972. Rather, surveys in 1973 and 1974 still showed no macroinvertebrates, and not until 1975 were any benthic organisms found in Silver Bow Creek (Chadwick et al., 1986). Recovery has proceeded slowly since then (Chadwick et al., 1986).

Natural recovery of Silver Bow Creek will proceed extremely slowly, in spite of anticipated response actions. Response actions underway or anticipated for Silver Bow Creek include (Montana NRDLP and Rocky Mountain Consultants, 1995):

- Collection and treatment of contaminated groundwater discharges to Silver Bow Creek in the Butte area.

- Removal/reclamation of waste dumps and other mining/milling sites in the Butte area.

- Collection and treatment of stormwater runoff to Silver Bow Creek.

- Partial removal of large tailings impoundments along the upper Silver Bow Creek.

- *In situ* treatment (i.e., lime stabilization) of floodplain tailings downstream of the Colorado Tailings.

However, these response actions will not address contaminated Silver Bow Creek bed sediments (described in Chapter 3.0) or large volumes of tailings and contaminated soils in the Silver Bow Creek floodplain. As described in Chapter 2.0, these contaminated sediments and soils will continue to serve as sources of hazardous substances to Silver Bow Creek for many years. Furthermore, contaminated groundwater will continue to discharge hazardous substances, including metals, to Silver Bow Creek near Lower Area One (see Chapter 4.0).

Benthic macroinvertebrates in the Clark Fork River will also continue to accumulate hazardous substances, thereby exposing fish which feed on them. In the Clark Fork River, Response actions underway or anticipated include (Montana NRDLP and Rocky Mountain Consultants, 1995):

- Reconstruction of the Mill-Willow Bypass around the Warm Springs Ponds.

- Upgrading of the Warm Springs Ponds treatment system.

- *In situ* treatment (i.e., lime stabilization) of streamside tailings from downstream of the Warm Springs Ponds to Deer Lodge.

These response actions do not address the large volumes of contaminated floodplain sediments downstream of Deer Lodge or contaminated bed sediments. Therefore, benthic macroinvertebrates and periphyton in the Clark Fork River will continue to be exposed to an accumulate hazardous substances.

Because hazardous substances will continue to be released to Silver Bow Creek and the Clark Fork River following response actions and contaminated bed sediments are not being addressed, recovery of benthic macroinvertebrates will proceed extremely slowly. Furthermore, the hazardous substances being released (including arsenic, cadmium, copper, lead, and zinc) are not naturally degraded or decomposed. Although their forms and bioavailability may be altered by both biological and physico-chemical processes (such as adsorption, complexation, and precipitation), they can not be degraded into nonhazardous substances (Manahan, 1994). Therefore, benthic macroinvertebrates in Silver Bow Creek and the Clark Fork River will continue to be exposed to hazardous substances for many years.

5.5 SUMMARY

The benthic macroinvertebrate community throughout Silver Bow Creek is injured. Silver Bow Creek sediments are toxic to a variety of organisms in controlled laboratory experiments. Both the total number of taxa and the density of the metals-sensitive Ephemeropterans, which are indices for measuring impacts to benthic communities from metals contamination, are significantly reduced relative to control streams. Concentrations of hazardous substances throughout Silver Bow Creek are well above threshold levels at which severe adverse impacts to benthic macroinvertebrates are expected. Based on these results, the benthic macroinvertebrate resource is injured for the entire length of Silver Bow Creek. This injury represents a single harm caused by exposure to multiple hazardous substances.

Historical sampling of invertebrate communities shows that the benthic macroinvertebrates have been injured for many decades. Natural recovery of the macroinvertebrate community will proceed extremely slowly.

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6.0 FISHERIES

6.1 INTRODUCTION

The previous three chapters of this report (Chapter 3.0 — Sediments, Chapter 4.0 — Surface Water and Chapter 5.0 — Macroinvertebrates) have shown that fish habitat (i.e., surface water and sediments) and prey (benthic macroinvertebrates) in Silver Bow Creek and the Clark Fork River have been exposed to, and/or injured by, the hazardous substances arsenic, cadmium, copper, lead, and zinc. These hazardous substances are released from the Butte and Anaconda areas and are re-released via pathway mechanisms.

This chapter contains the assessment of injury to fishery resources of the Clark Fork River and Silver Bow Creek. This assessment focuses on *trout* because of their significant recreational and nonuse values; the State has not assessed injury to all species of fish. Thus, for the purposes of this report, "fishery resources" are defined as trout of various species.

Injuries to fishery resources in Silver Bow Creek and the Clark Fork River have been documented for many years. Historically, the Clark Fork River was contaminated with hazardous substances to the extent that no fish and few invertebrates were seen in the river from the late 1800s until the mid 1950s (Spindler, 1959; Johnson and Schmidt, 1988). Casne et al. (1975) reported a complete lack of biota in the Clark Fork River between Warm Springs Ponds and Dempsey, with the exception of two pollution-tolerant invertebrates, between 1970 and 1972. The trout population in the upper Clark Fork between Butte and Rock Creek currently is composed almost exclusively of brown trout (*Salmo trutta*) (Knudson, 1984; Johnson and Schmidt, 1988); rainbow trout (*Oncorhynchus mykiss*) rarely occur upstream of Rock Creek, over 100 river miles downstream of the Warm Springs Ponds.

This chapter is organized as follows: **Section 6.2, Pathway Determination**, identifies contaminated surface water, sediments, and macroinvertebrates as the pathways by which trout of the Upper Clark Fork River Basin are exposed to hazardous substances. **Section 6.3, Injury Definition**, identifies the types of injuries to the fisheries resource. **Section 6.4, Injury Determination**, describes testing performed to evaluate injuries to trout, and confirms that trout have been injured as a result of exposure to hazardous substances in the upper Clark Fork River Basin. Specifically: 1) fish kills have been documented in the Clark Fork River, 2) *In situ* bioassays performed in Silver Bow Creek and the Clark Fork River have demonstrated trout mortality, 3) controlled laboratory exposure to hazardous substances found in Silver Bow Creek and the Clark Fork River causes trout mortality, 4) trout avoid water containing hazardous substances at concentrations that occur in Silver Bow Creek and the Clark Fork River, 5) ingestion of contaminated macroinvertebrates from the Clark Fork River causes mortality and growth reductions in trout, and 6) trout suffer physiological health impairments, including growth reductions and physical deformation, as a result of chronic exposure to hazardous substances in surface water and macroinvertebrates. **Section 6.5, Injury Quantification**, quantifies injuries to trout in terms of measured population and

biomass reductions in Silver Bow Creek and the Clark Fork River relative to baseline conditions. Finally, **Section 6.6, Resource Recoverability,** discusses recovery of trout populations. **Section 6.7** presents literature cited.

6.2 PATHWAY DETERMINATION

The purpose of the pathway determination is to identify the route or media by which hazardous substances have been transported from their sources to the fish of the upper Clark Fork River Basin. Sources of hazardous substances are detailed in Chapter 2.0, and mechanisms by which hazardous substances are transported from sources to the surface water and sediments of Silver Bow Creek and the Clark Fork River are described in Chapter 3.0 (Sediments) and Chapter 4.0 (Surface Water). Chapter 5.0 (Benthic Macroinvertebrates) presented information of exposure to and uptake of hazardous substances by invertebrates that serve as prey for trout. Two distinct pathways result in exposure of fish to hazardous substances (Figure 6-1):

- **Surface Water Pathway.** This pathway involves direct contact by trout with hazardous substances in surface water. The contact mechanism involves exposure to hazardous substances in water that flows across the gills or, in the case of avoidance behaviors, olfactory sensation of hazardous substances in water.

- **Food Chain Pathway.** This pathway involves contact with hazardous substances through consumption of contaminated food. Benthic macroinvertebrates accumulate hazardous substances from contaminated sediments, surface water, and periphyton (see Chapter 5.0). These invertebrates, when consumed by trout, serve as a dietary exposure pathway.

These two principal pathways are described briefly below in Sections 6.2.1 and 6.2.2. Data demonstrating the presence of hazardous substances in surface water, sediments, and benthic macroinvertebrates are presented in Chapters 3.0 through 5.0.

6.2.1 Surface Water Pathway

A discussion of the sources, transport pathways, and rate of transport of hazardous substances in surface water can be found in Chapters 2.0 and 4.0. A brief summary is included in this section.

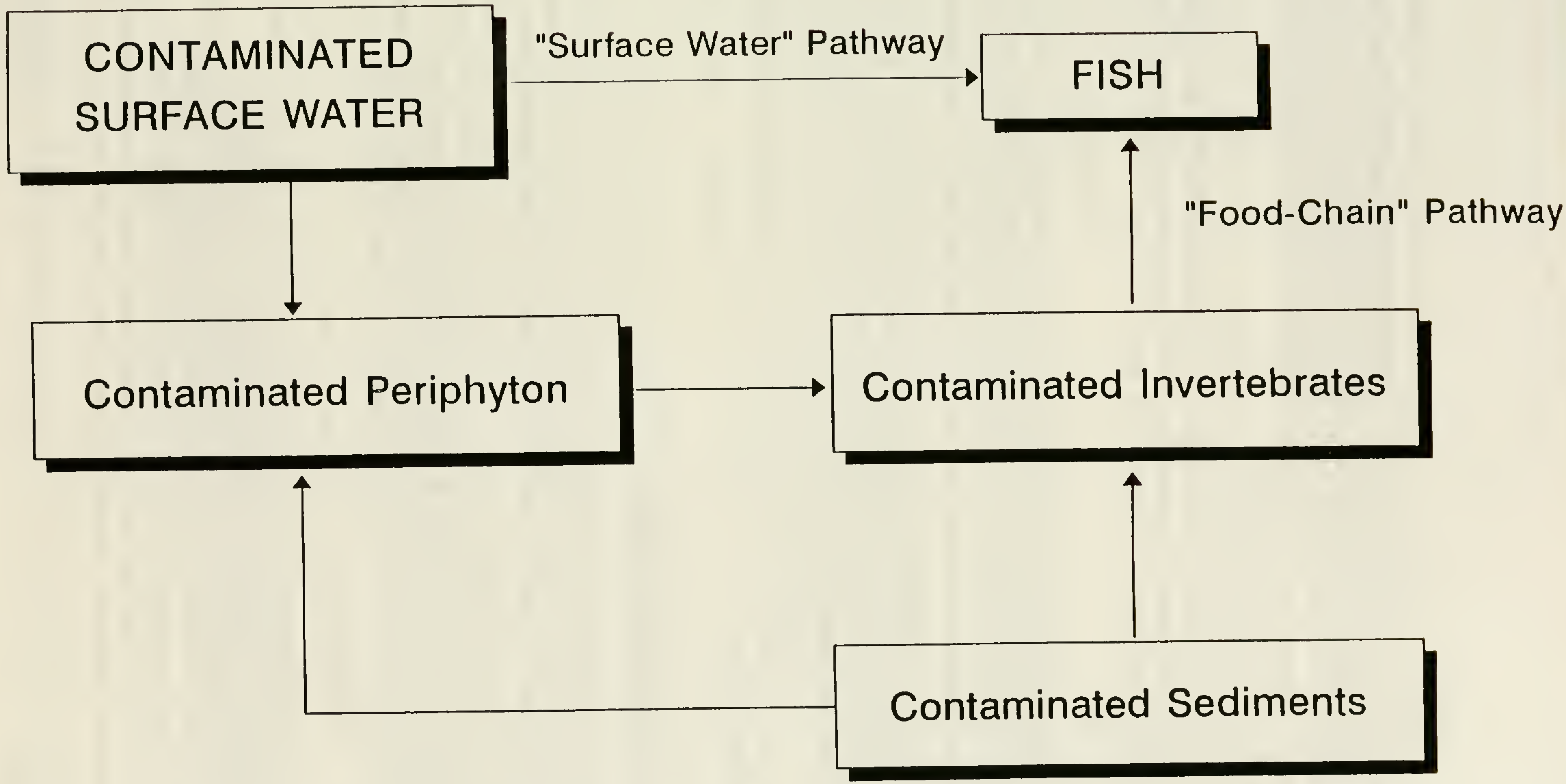

Figure 6-1. Pathways by Which Fish are Exposed to Hazardous Substances.

Surface water resources of Silver Bow Creek and the Clark Fork River have been exposed to and injured by the hazardous substances cadmium, copper, lead, and zinc. In Silver Bow Creek, concentrations of copper and zinc have exceeded both acute and chronic ambient water quality criteria in virtually 100% of all samples collected. Chronic criteria have been exceeded regularly for lead and cadmium.

In the Clark Fork River, copper concentrations have regularly exceeded acute and chronic criteria, although the frequency of exceedences, as well as the measured concentrations, are lower than in Silver Bow Creek. Concentrations of both zinc and lead have also exceeded water quality criteria.

Hazardous substances have been and continue to be carried downstream to the Clark Fork River by Silver Bow Creek and the Warm Springs Ponds discharge. Hazardous substances are transported in surface waters in both dissolved and particulate forms. Particulate forms are transported as tailings, other mining wastes, and as contaminated soils and sediments. Large amounts of these materials have been carried downstream by the Clark Fork River and deposited in bed, bank, and floodplain sediments, and the Milltown Reservoir. Floodplain deposits and riverside tailings act as continuous secondary sources to Clark Fork River bed sediments and surface waters through erosion and runoff.

Thus, surface water contaminated with hazardous substances from sources and from pathways serve as a pathway to fish.

6.2.2 Sediment/Food Chain Pathway

The sediments and periphyton of Silver Bow Creek and the Clark Fork River from the Warm Springs Ponds to Milltown are highly contaminated with the hazardous substances arsenic, cadmium, copper, lead, and zinc as a result of large-scale mining and mineral processing operations in the Butte and Anaconda areas. As shown in Chapter 3.0, median concentrations of copper, cadmium, zinc, lead and arsenic in Silver Bow Creek fine-grained sediments are approximately 500, 150, 150, 100, and 80 times greater than baseline conditions, respectively. In Clark Fork River sediments, median concentrations of copper, cadmium, zinc, arsenic, and lead are approximately 65, 35, 27, 20, and 11 times greater than baseline concentrations, respectively.

Benthic macroinvertebrates live in and on bed sediments and thus are exposed directly to hazardous substances contained in sediments and periphyton. These benthic macroinvertebrates play essential roles in aquatic ecosystems, including serving as a primary food source for trout. As shown in Chapter 5.0, benthic macroinvertebrates contain significantly elevated concentrations of the hazardous substances arsenic, cadmium, copper, lead, and zinc, relative to baseline conditions. In addition, Chapter 5.0 demonstrates that the hazardous substances contained in sediments of Silver Bow Creek and the Clark Fork River

are biologically available to aquatic organisms, that macroinvertebrates have been found to accumulate hazardous substances in both field and controlled laboratory studies, and that concentrations of hazardous substances in macroinvertebrates are correlated with the concentrations in sediments to which they have been exposed.

Thus, contaminated sediments and periphyton act as the principal pathway of hazardous substances to benthic macroinvertebrates which, in turn, serve as a pathway to fish via food chain exposures.

6.3 INJURY DEFINITION

The following section identifies the injuries to fishery resources resulting from hazardous substances in Silver Bow Creek and the Clark Fork River, as well as describing accepted methodologies for determining these injuries.

An injury to fish has resulted if one or more of the following changes has occurred: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62 (f)(1)]. The following types of injury — all of which have been determined by the U.S. DOI to have met the acceptance criteria for injury — have been assessed by the State:

Category of Injury : Death [43 CFR § 11.62 (f)(4)(i)]

- A significant increase in the frequency or numbers of dead or dying fish can be measured in fish kill investigations [43 CFR § 11.62 (f)(4)(i)(B)].

- A statistically significant difference can be measured in the total mortality and/or mortality rates in *in situ* bioassays [43 CFR § 11.62 (f)(4)(i)(D)].

- A statistically significant difference can be measured in the total mortality and/or mortality rates between population samples of test organisms placed in laboratory exposure chambers containing concentrations of hazardous substances and those in a control chamber [43 CFR § 11.62 (f)(4)(i)(E)].

Category of Injury : Behavioral Abnormalities [43 CFR § 11.62 (f)(4)(iii)]

- A statistically significant difference can be measured in the frequency of avoidance behavior in population samples of fish placed in a testing chambers with equal access to water containing... a hazardous substance and water from the control area [43 CFR § 11.62 (f)(4)(iii)(B)].

Category of Injury: Reduced Growth and Health Impairment

Growth is considered to be an endpoint, or indicator, of effects on reproduction and toxicity (U.S. FWS and University of Wyoming, 1987). In addition, reduced growth has been found in this assessment to satisfy the four acceptance criteria for biological responses [43 CFR § 11.62(f)(2)(i-iv)]. Specifically, reduced growth is:

- Often the result of exposure to hazardous substances, as shown in various scientific studies
- Caused in free-ranging organisms by exposure to hazardous substances
- Found in controlled laboratory experiments by exposure to hazardous substances
- A routine measurement that is practical to perform and produces scientifically valid results.

In addition, the following physiological health impairment injuries were evaluated in fish:

- Gut impaction and constipation
- Physiological degeneration of the digestive system and cell loss
- Lipid peroxidation
- Histopathological deformation.

Each of these health impairments likely causes reduced survival in the field, and can contribute to overall population reductions. The following section (Section 6.4 — Injury Determination) shows that the above injuries to fish have been caused by exposure to hazardous substances.

6.4 INJURY DETERMINATION: TESTING AND SAMPLING

This section presents the determination, based on the results of field and laboratory testing and sampling, that fishery resources of the Silver Bow Creek and the Clark Fork River have been injured as a result of releases of hazardous substances.

6.4.1 Background: Impacts of Hazardous Metals on Fish and Overview of Injury Determination Studies

The hazardous substances copper, cadmium, lead, and zinc are known to cause a number of toxic injuries to fish, including death, behavioral avoidance, physiological damage, and

reduced growth. As described below, there is extensive scientific literature documenting these toxic effects on salmonids and other aquatic biota. As described in Chapter 4.0, the U.S. EPA has promulgated ambient water quality criteria for each of these hazardous substances for the protection of aquatic life.

Death

Copper, cadmium, lead, and zinc have all been shown to cause lethality in trout (e.g., Cusimano et al., 1986; Mount, 1966; Watson and Beamish, 1980; Chakoumakos et al., 1979; Benoit et al., 1976; Carroll et al., 1979; Hodson et al., 1979 and 1983; Bradley and Sprague, 1985; Everall et al., 1989). The primary mechanisms of metal-induced mortality are disruption of ionoregulation and respiratory failure. The gills are the primary site of ionoregulation (Evans, 1987), the process that drives many cellular metabolic functions. Hazardous metals can disrupt ionoregulation by injuring the gill membrane so that ions (e.g., sodium) leak across the membrane, and by disrupting necessary enzymes (Lauren and McDonald, 1985; 1986). Continued disruption of ionoregulation leads to mortality.

The gills are also the primary site of respiration (Evans, 1987). Exposure to hazardous metals causes physiological damages to respiratory gill tissues (Wilson and Taylor, 1993). This damage impairs the transfer of respiratory gases (e.g., oxygen) by increasing the distance that respiratory gas must diffuse across between blood and water (Hughes and Perry, 1976; Satchell, 1984; and Mallatt, 1985; all as cited in Wilson and Taylor, 1993) causing asphyxiation, cardiovascular failure (Wilson and Taylor, 1993), and death.

In this assessment, mortality caused by hazardous substances is demonstrated using a number of tests:

- **Fish kills** have been observed in the Clark Fork River (Silver Bow Creek does not support fish; therefore fish kills do not occur).

- ***In situ* bioassays.** Studies were conducted in which trout were placed in cages in Silver Bow Creek and the Clark Fork River. Significant mortality was observed in fish placed in Silver Bow Creek and the Clark Fork River relative to controls.

- **Laboratory bioassays.** Laboratory studies were performed to evaluate the lethality of short-term, acute exposures to hazardous metals at concentrations similar to those that occur in the Clark Fork River and Silver Bow Creek. In addition, laboratory studies were performed to evaluate the effects on trout survival of consumption of metals-contaminated invertebrates collected from the Clark Fork River.

Behavioral Avoidance

A number of metals have been shown to cause behavioral avoidance in trout, including copper (e.g., Giattina et al., 1982), cadmium (e.g., McNicol and Scherer, 1991), and zinc (e.g., Saunders and Sprague, 1967). Field studies have demonstrated avoidance of waters contaminated with mine wastes containing copper and zinc (Saunders and Sprague, 1967), causing reductions in salmonid populations.

Laboratory testing was performed to evaluate whether trout avoid metals at concentrations similar to those found in the Clark Fork River.

Physiological Impairment and Reduced Growth

Exposure to hazardous metals also can cause physiological impairment injuries to fish. For example, copper has been found to cause injuries to liver cells (including fragmentation of the endoplasmic reticulum, damage to nuclear components, and rupture of plasma and nuclear membranes) (Leland, 1983), and kidney cells (Vogel, 1959; Kaer, 1969; Gardner and LaRoche, 1973; as cited in Lauren and McDonald, 1985). Cadmium has been shown to cause both respiratory impairment (Pascoe, 1977; McCarty et al., 1978; as cited in Sorenson, 1991), as well as muscular and/or neural abnormalities (e.g., Bengtsson et al., 1975; Pascoe and Mattey, 1977; as cited in Sorenson, 1991). Zinc has been shown to cause histopathological lesions and inhibition of spawning (Sorenson, 1991).

In addition to physiological impairments, reduced growth has been documented during sublethal exposures to a mixture of zinc and copper (Finlayson and Verrue, 1980), to zinc alone (Hobson and Birge, 1989), copper alone (Dixon and Sprague, 1981), and a mixture of copper, zinc, and cadmium (Roch and McCarter, 1984; Roch and McCarter, 1986). In these studies, reduced growth was considered to be a sensitive measure of the deleterious effect of these metals.

For this assessment, laboratory testing (including exposures to hazardous substances in water and through consumption of contaminated invertebrates collected from the Clark Fork River) was performed to evaluate the effects of metal exposure on:

- Growth
- Cell histopathology (microscopic examination of cellular damage)
- Gross physiological abnormalities
- Metal accumulation in fish tissues
- Chemical indicators of metals stress (metallothionein, lipid peroxidation).

These indicators of adverse metals effects were also evaluated in field studies using free ranging trout collected from the Clark Fork River and from control sites.

Organization of Injury Determination Studies

Figure 6-2 depicts the overall organization of the injury determination studies. As shown in the figure, injury determination studies included both a field and a laboratory component. The field components (including documentation of fish kills, *in situ* bioassays, fish health impairment studies) provide direct and compelling evidence of injuries to trout under actual ambient conditions. The laboratory components (lethality, acclimation/adaptation, behavioral avoidance, physiological impairment and reduced growth) provide clear documentation of the causal relationship between exposure to the hazardous substances and the observed adverse effects under controlled conditions using rigorous testing procedures. In addition, the laboratory testing was used to identify diagnostic indicators of metal-induced injuries that were then related to conditions observed in the field.

The multiple injuries sustained by Silver Bow Creek/Clark Fork River fish (death, avoidance, physiological impairment, reduced growth) contribute to overall reductions in trout populations. These population reductions were measured directly in the field using fish population quantification procedures.

Testing Conditions Used for Injury Determination Studies

Fish kills and *in situ* bioassays evaluate injuries under ambient conditions. Laboratory toxicity studies were performed using conditions similar to those observed in Silver Bow Creek and the Clark Fork River. Conditions that have shown to be important in toxicity testing include water hardness, exposure duration, test species, life stage and fish size, and laboratory testing procedures.

1. Hardness

Hardness is defined as the sum of calcium and magnesium concentrations, expressed as calcium carbonate ($CaCO_3$). Hardness (and alkalinity) are dominant influences on the toxicity of copper (Lauren and McDonald, 1986). The U.S. EPA's AWQC for cadmium, copper, lead, and zinc are expressed as a function of water hardness. It has been observed by a number of authors that as hardness increases, metal toxicity decreases. This relationship is caused by three distinct factors: (1) the increase in calcium and magnesium ions in water associated with increasing hardness can compete with metals for binding sites at the gill surface (Pagenkopf, 1983); (2) as carbonate concentrations increase (with increasing alkalinity, which is often associated with increasing hardness), freely dissolved metal species have an increased tendency to form carbonate complexes (Stiff, 1971; Lauren and McDonald, 1986), which are generally less toxic than freely dissolved metal species; and (3) calcium is known to decrease the permeability of tissues (Hunn, 1985), thus reducing ionoregulatory impairment (Lauren and McDonald, 1986). Because of the known relationship between metal toxicity and hardness, injury determination laboratory testing was performed at hardnesses similar to those observed in the Clark Fork River.

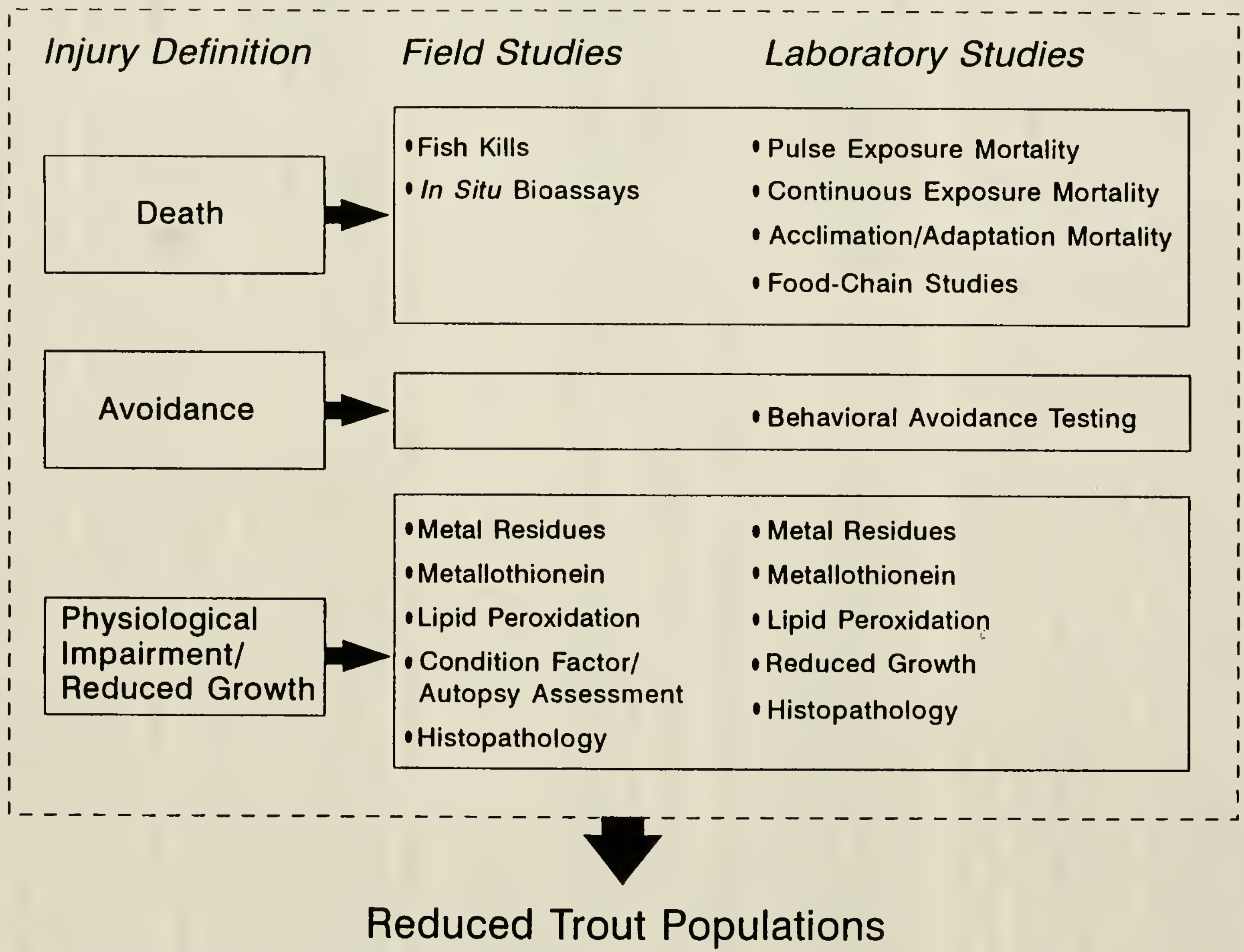

Figure 6-2. Overview of Injury Determination Studies.

2. Effects of Exposure Duration on Toxicity

Available data indicate that as the duration of exposure increases, the concentration of metal that causes mortality decreases (assuming all other factors are held constant). For example, in the development of the AWQC for copper, the U.S. EPA reviewed available data for all aquatic life and concluded that chronic (long-term) exposures to copper cause toxicity at lower concentrations than acute (short-term) exposures (U.S. EPA, 1985). This is reflected in the acute and chronic AWQC: at a hardness of 100 mg/l as $CaCO_3$, the acute AWQC is 1.5 times greater than the chronic AWQC.

The exposure duration of concern for trout in the Clark Fork River includes both short-term acute exposures and long term chronic exposures over the entire life-span of a fish. Trout in the Clark Fork River are exposed continually to elevated concentrations of hazardous substances (see Chapter 4.0). In addition, trout are exposed to extremely elevated concentrations for shorter periods during thunderstorms and other "pulse" exposures (see Chapter 4.0). Laboratory injury determination testing evaluated the following exposure regimes and responses:

- The effects of short-term pulse exposures to hazardous metals on trout survival
- The effects of short-term continuous exposures to hazardous substances on trout survival
- The effects of longer-term continuous exposures to hazardous substances on trout growth and physiological health
- The effects of longer-term continuous exposures to hazardous substances in contaminated invertebrate diets on trout survival, growth, and physiological health.

In addition, *in situ* field studies evaluated trout survival over longer-term (3 month) ambient exposures.

3. Test Species

Selection of test species and procedures can affect the results of laboratory toxicity testing. The sensitivity of standard laboratory test organisms can vary substantially (see, for example, U.S.EPA, 1985). Because trout were the primary species of concern for the assessment, all laboratory testing was performed using trout, including hatchery strains of both brown and rainbow trout. In addition, laboratory testing was performed using brown trout collected from the Clark Fork River to evaluate whether these trout have substantially different tolerance to hazardous metals than hatchery strains.

4. Effects of Life Stage and Fish Size on Toxicity

Another factor that influences toxicity is the life stage or size of the fish. Several studies have examined the effects of trout size on sensitivity to metal. Overall, these studies show an increase in resistance with increased size. A study of brown trout found that adults were able to spawn successfully at 32.5 and 17.4 µg/l copper even though these levels proved lethal to their young (McKim and Benoit, 1971). Other data show that for mortality as the endpoint, younger, smaller fish are generally the most sensitive to metal toxicity (e.g., (McKim and Benoit, 1971; McKim et al., 1978). Chakoumakos et al. (1979) and Howarth and Sprague (1978) have noted that larger rainbow trout (~ 10 - 30g) are some 2.5 - 3.0 times more resistant than smaller trout (as cited in U.S. EPA, 1985).

For determining injury to fish in the Clark Fork River, the most sensitive life stages are of primary importance because they serve as a bottleneck on overall trout populations. Injury determination testing was performed using both early life stage ("fry") and older ("juvenile") trout. It should be recognized, however, that injuries documented to juvenile trout in laboratory testing would be expected to occur in earlier life stage fish at lower concentrations.

5. Laboratory Testing Procedures

All testing was performed using standardized laboratory procedures. 43 CFR § 11.62 (f)(4)(i)(E). Department of Interior regulations note that "The . . . hazardous substance used in the test must be the exact substance or a *substance that is reasonably comparable* to that suspected to have caused . . . (injury) . . . to the natural population of fish." See 43 CFR § 11.62 (f)(4)(i)(E), 43 CFR § 11.62 (f)(4)(iii)(B) (emphasis added). The bioassay studies were performed using mixtures of cadmium, copper, lead, and zinc, the principal hazardous substances suspected of injuring fishery resources.

In addition, laboratory testing was performed at hardness, alkalinity, and pH conditions measured in the Clark Fork River. Therefore, exposure conditions were comparable to ambient field conditions. Food-chain testing was performed using contaminated invertebrates collected from the Clark Fork River. Therefore, conditions in these tests were comparable to ambient field conditions.

Standard laboratory toxicity testing procedures include static, static-renewal, and flow-through (or continuous flow) testing. Static testing involves exposing fish to a water sample that is not changed for the duration of the testing. Static renewal testing is similar to static testing, however the test water is changed several times during the study (for example, once every 24 hours). Flow-through testing involves maintaining a continuous flow of water — at relatively constant water quality conditions — through the test containers for the duration of the testing.

The advantages of continuous-flow technique over static or static-renewal techniques have been emphasized by leaders in the field of aquatic toxicology for many years. For example, Brungs (1973) indicates that if toxic exposures are continuous "continuous-flow bioassays *will have to be* conducted." Similarly, Rand and Petrocelli (1985) note that "the flow-through procedure should be used wherever possible. This results in more uniform and stable test conditions, with the test material concentration, dissolved oxygen concentration, and other water quality characteristics remaining relatively constant while the waste products are removed. Although flow-through tests may involve a more complex delivery system, they yield the best and most accurate estimate of toxicity. . . . Cause-and-effect relationships can thus be more easily established." For this assessment, laboratory toxicity testing was performed using the more rigorous flow-through testing procedure.

Finally, all laboratory studies were designed to be conducted in accordance with Good Laboratory Practice Standards outlined in the Federal Register (160.120; 40 CFR Part 160, 7-1-85 edition; subpart G - "Protocol for and conduct of a study").

6.4.2 Category of Injury: Death/Fish Kill Investigations

Fish kills have not been documented in Silver Bow Creek, because Silver Bow Creek does not support a fish population (see Section 6.5; Johnson and Schmidt, 1988).

Fish kills in the Clark Fork River have occurred regularly. Phillips (1992) compiled a review of observed Clark Fork River fish kills between 1959 and 1991. Averett (1961) reported on fish kills in the Clark Fork River between 1958 and 1960. Between 1983 and 1991 there were at least eight documented fish kills in the upper Clark Fork River, some killing several thousand fish (Phillips, 1992) (Table 6-1). Most of the observed fish kills occurred in association with summer thunderstorms, when runoff across floodplain tailings deposits releases pulses of hazardous substances. As indicated in Table 6-1, fish kills have been observed from the Mill-Willow Bypass (at the Warm Springs Ponds) as far downstream as Rock Creek, and have resulted in mortality to trout and other fish species, including both juvenile and adult fish.

Most fish kills that have been observed in the Clark Fork River were investigated by the State Pollution Control Biologist or other trained State personnel, following the guidance of the Montana DFWP and Montana DHES (1988) fish kill investigation document (G. Phillips, Montana DFWP, *pers. comm.*).

Many of the reports listed in Table 6-1 provide water quality data and/or hazardous substance residue data from dead fish. These data, coupled with the occurrence of fish kills following thunderstorms that are known to release pulses of metals into the river, clearly indicate that the fish kills were caused by hazardous substances, including copper, zinc, and other

Table 6-1
Documented Fish Kills in the Clark Fork River, 1959-1991
(Compiled by Phillips, 1992)

Date	Location; Details
December 1, 1959[1]	Near Rock Creek; at least 17 fish found, including whitefish, suckers, shiners, and squawfish
July 30, 1962[1]	Between Warm Springs and Racetrack; 39 dead fish counted, 650 total dead estimated
August 23, 1973[2]	Near Deer Lodge; several hundred adult fish (all species) and several thousand juvenile fish dead after thunderstorm
August 9, 1983[3]	Near Perkins Lane Bridge; associated with heavy thunderstorm
August 2, 1984[4]	Mill-Willow Bypass to Racetrack; over 10,000 fish (estimated) killed after heavy thunderstorm
June 18, 1987[2]	Near Lost Creek Bridge; approximately 50 brown trout dead after thunderstorm
July 3, 1987[5]	Near Mill-Willow Bypass & downstream of Warm Springs Ponds
May 27, 1988[2]	Near Mill-Willow Bypass; trout, suckers, whitefish killed after thunderstorm
July 12, 1989[6]	Mill-Willow Bypass to Deer Lodge; over 5,000 fish killed after thunderstorm
July 2, 1990[7]	Mill-Willow Bypass near Hog Hole; 100 juvenile brown trout, whitefish, and suckers kill after thunderstorm
August 20, 1991[2]	Below Racetrack Creek Bridge; over 200 fish killed (mostly brown trout) after intense thunderstorm

1 Averett, 1960.
2 Phillips, 1992.
3 Phillips, 1983.
4 Pedersen and Phillips, 1984.
5 Phillips, 1987.
6 Phillips and Kerr, 1989.
7 Spoon, 1990.

hazardous substances (e.g., lead, cadmium).[1] For example, the 1989 fish kill in Mill-Willow Bypass and the Clark Fork from Warm Springs Ponds to Deer Lodge (Phillips and Kerr, 1989) occurred when copper and zinc in the water were substantially greater than acute Ambient Water Quality Criteria (AWQC) (see Chapter 4.0). In the Mill-Willow Bypass, concentrations of copper and zinc were both two *orders of magnitude* (i.e., at least one hundred times) greater than the acute AWQC. Copper concentrations were well above the AWQC in the Clark Fork River at Warm Springs Bridge, Perkins Lane Bridge, and Galen, and were still greater than the AWQC a full day after the thunderstorm (Phillips and Kerr, 1989).

Hazardous substance residues in brown trout killed in the 1989 kill were extremely elevated. Fish killed in the Mill-Willow Bypass contained extremely elevated concentrations of cadmium, copper, and zinc in the gills; the mean gill concentrations of four fish tested were 5.6 ppm Cd, 683 ppm Cu, and 888 ppm Zn (dry weight). By comparison, brown trout collected from control streams contained mean gill concentrations of 0.3 ppm Cd and 9 ppm Cu (dry weight) (see Section 6.4.8).

Elevated concentrations of hazardous substances in both water and fish tissue have been documented for other fish kills as well (i.e., Pedersen and Phillips, 1984; Phillips, 1988; Phillips, 1992), providing further confirmation that the cause of these fish kills in the Mill-Willow Bypass and the upper Clark Fork River has been releases of hazardous substances. Section 6.4.4 describes controlled laboratory toxicity studies that document the acute lethality of pulses of hazardous substances similar to those measured during fish kills.

The observed fish kills in the Clark Fork River provide clear evidence of injuries to trout (and other fish) under ambient conditions.

6.4.3 Category of Injury: Death/*In Situ* Bioassays

The NRDA technical guidance document for assessing injury to fish (U.S. FWS and University of Wyoming, 1987) states that "the scientific literature is very convincing in demonstrating the utility of *in situ* (caged fish) bioassays for assessing the effects of...hazardous substances on fish mortality." In-stream bioassays have been conducted at various locations in the Clark Fork River. Averett (1960) placed three live-boxes containing rainbow trout in the Clark Fork River ten miles upstream of Milltown Reservoir and three miles downstream of the Reservoir, as well as at a control site in Rattlesnake Creek. In less than three days, all trout in the Clark Fork River died, and a reddish-orange precipitate coating the gills was observed. All the trout in Rattlesnake Creek survived.

[1] By-products of hazardous substance releases (e.g., pH) may also have contributed to fish kills.

Recent *in situ* fish bioassays have been conducted in both the Clark Fork River and in Silver Bow Creek. Phillips and Spoon (1990) reported results of *in situ* testing in Silver Bow Creek and the Clark Fork River over a four year period (1986-1989); the same authors conducted additional testing during 1990. Tests were conducted during the spring runoff period (mid-April to early July) using rainbow trout fingerlings (1986, 1987) and swim-up fry (1987-1990). The tests were conducted by placing fish in holding containers in the sampling locations. The fish were fed (with automatic feeding devices) commercial trout food throughout the test period. The authors found that mortality of rainbow trout fingerlings and fry in Silver Bow Creek and in many Clark Fork River sites was significantly higher than at control sites (Racetrack Creek and the Little Blackfoot River) (Table 6-2). The average copper and zinc concentrations over the testing period were one or two *orders of magnitude* higher in Silver Bow Creek than in controls; mortality was close to 90% in testing performed in 1986 and 1987, and 100% in tests performed in 1988 and 1990 (in 1989 testing, 68% of the trout died in the first day and the site was vandalized on the second day).

Similarly, significant mortality was observed in the Clark Fork River during every year of testing. Mortality rates varied by site and by year (in part because the three-month ambient testing integrates both continuous exposure and spatially and temporally variable pulse exposures of metals). However, mortality rates as high as 64% were documented in the Clark Fork River. Significant mortality occurred in at least two sites in every year of testing and in every site at least one of the five years of testing (Table 6-2).

As with the fish kills, the significant trout mortality observed in Silver Bow Creek and the Clark Fork River in the *in situ* bioassays provides clear evidence confirming that ambient conditions cause trout mortality, and that the mortality was caused by hazardous substances.[2] Moreover, trout mortality was observed each year over the five-year testing period demonstrating the ongoing injuries to fishery resources. Again, exposure to the hazardous substances measured in Silver Bow Creek and the Clark Fork River is the only plausible explanation for this consistent mortality. The following sections provide additional laboratory confirmation that the hazardous substances found in Silver Bow Creek and the Clark Fork River are toxic to both rainbow and brown trout.

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[2] The testing was conducted during the spring-flow period. It is implausible, based on many years of surface water sampling data, that either dissolved oxygen or elevated temperature (two putative causes of fish mortality in rivers) contributed to the observed mortality; during spring conditions, both dissolved oxygen and temperature consistently are within ranges that do not adversely affect trout (see Appendix A). The only plausible explanation for the mortality is exposure to hazardous metals.

Table 6-2
Results of Five Years of *In Situ* Bioassays in the Clark Fork River and Silver Bow Creek and Control Sites, Using Fry and/or Fingerling Rainbow Trout

Location	Copper[1] (mean, range µg/l)	Zinc[1] (mean, range µg/l)	Hardness (mean, range mg/l)	Cum. % Mortality	
				Fry	Fingerling
1986					
Racetrack Creek+	5 (5-10)	7 (3-15)	83 (28-116)	--	0
Silver Bow Creek	201 (90-690)	381 (154-770)	104 (78-122)	--	89*
CFR at Warm Springs	39 (5-110)	96 (35-308)	128 (80-200)	--	25*
CFR at Deer Lodge	59 (20-140)	67 (24-130)	177 (96-224)	--	15*
CFR at Gold Creek	55 (10-160)	60 (19-163)	145 (94-170)	--	7
CFR at Beavertail	55 (5-170)	83 (24-223)	155 (110-184)	--	21*
CFR at Clinton	28 (5-70)	44 (9-105)	103 (70-124)	--	3
1987					
Racetrack Creek+	6 (5-10)	12 (6-24)	110 (98-122)	8	2
Silver Bow Creek	219 (70-520)	478 (32-994)	116 (104-124)	92*	88*
CFR at Warm Springs	28 (10-50)	99 (27-430)	169 (140-216)	18	7
CFR at Gold Creek	14 (5-30)	35 (19-57)	172 (124-204)	36*	24*
CFR at Beavertail	15 (5-40)	31 (4-54)	192 (100-228)	55*	12*
CFR at Clinton	8 (5-20)	17 (2-30)	113 (64-148)	10	8

Note: Mortality is the cumulative mortality. CFR = Clark Fork River.

1 Concentrations are Montana Total Recoverable
* Significantly higher mortality than control site (α = 0.05).
\+ Control location.

Source: Phillips and Spoon, 1990.

Table 6-2 (cont.)
Results of Five Years of *In Situ* Bioassays in the Clark Fork River and Silver Bow Creek and Control Sites, Using Fry and/or Fingerling Rainbow Trout

Location	Copper[1] (mean, range µg/l)	Zinc[1] (mean, range µg/l)	Hardness (mean, range mg/l)	Cum. % Mortality Fry	Cum. % Mortality Fingerling
1988					
Racetrack Creek[+]	1 (1-5)	8 (5-24)	95 (38-110)	0	--
Little Blackfoot River[+]	1 (1-2)	5 (5-10)	104 (80-130)	6	--
Silver Bow Creek	254 (110-2,200)	605 (286-3,740)	129 (102-154)	100*	--
Mill-Willow Bypass	39 (5-220)	52 (9-284)	153 (80-262)	22*	--
CFR at Warm Springs	30 (10-68)	57 (21-165)	154 (114-202)	7	--
CFR at Beck Hill	32 (10-94)	44 (10-127)	209 (166-252)	6	--
CFR at Gold Creek	24 (7-63)	34 (7-81)	175 (126-216)	5	--
CFR at Beavertail	25 (3-71)	42 (5-109)	199 (160-230)	16*	--
CFR at Clinton	17 (6-34)	36 (5-105)	107 (84-142)	0	--
1989					
Racetrack Creek[+]	1 (1-3)	6 (5-22)	95 (42-118)	2	--
Silver Bow Creek	--	--	--	68*	--
CFR at Beck Hill	27 (10-70)	44 (19-83)	196 (160-236)	25*	--
CFR at Gold Creek	18 (8-40)	28 (12-53)	157 (116-206)	33*	--
CFR at Beavertail	19 (4-60)	37 (8-97)	180 (128-228)	64*	--
CFR at Clinton	10 (3-20)	20 (6-38)	128 (98-224)	6	--

Note: Mortality is the cumulative mortality. CFR = Clark Fork River.

1 Concentrations are Montana Total Recoverable
* Significantly higher mortality than control site ($\alpha = 0.05$).
+ Control location.

Source: Phillips and Spoon, 1990.

Table 6-2 (cont.)
Results of Five Years of *In Situ* Bioassays in the Clark Fork River and Silver Bow Creek and Control Sites, Using Fry and/or Fingerling Rainbow Trout

Location	Copper[1] (mean, range µg/l)	Zinc[1] (mean, range µg/l)	Hardness (mean, range mg/l)	Cum. % Mortality	
				Fry	Fingerling
1990					
Racetrack Creek[+]	1 (1-5)	3 (2-6)	73 (38-110)	1	--
Silver Bow Creek	235 (109-842)	521 (57-1,950)	129 (112-182)	100*	--
Mill-Willow Bypass	24 (9-42)	51 (27-103)	381 (108-722)	36*	--
CFR at Warm Springs	24 (17-35)	36 (21-56)	165 (128-186)	32*	--
CFR at Beck Hill	36 (16-112)	46 (19-141)	201 (154-238)	13*	--
CFR at Gold Creek	23 (12-63)	30 (8-79)	141 (118-176)	3	--
CFR at Beavertail	30 (2-96)	50 (13-156)	173 (144-234)	10*	--
CFR at Clinton	14 (4-33)	22 (5-63)	103 (74-126)	8*	--

Note: Mortality is the cumulative mortality. CFR = Clark Fork River.

1 Concentrations are Montana Total Recoverable
* Significantly higher mortality than control site ($\alpha = 0.05$).
\+ Control location.

Source: Phillips and Spoon, 1990.

6.4.4 Category of Injury: Death/Acute Lethality from Exposure to Pulsed Hazardous Substances

Laboratory acute toxicity tests have been used extensively to show the toxicity of hazardous substances to fish (Rand and Petrocelli, 1985). The NRDA technical guidance document for determining fish injury (U.S. FWS and University of Wyoming, 1987) states that "...laboratory toxicity tests... for the detection of fish death response are the most thoroughly validated of all fish injury responses considered." A number of distinct laboratory toxicity tests were performed to evaluate the effects of hazardous substances on fish; this section examines the acute lethality of pulsed concentrations of hazardous substances on trout.

As described in Chapter 4.0, episodic spikes, or "pulses," of extremely elevated concentrations of hazardous metals are released to the Clark Fork River. These pulses often are associated with thunderstorms that mobilize metals from streamside tailings (Brooks, 1988), and have been shown to cause fish kills in the Clark Fork River. In addition, physical conditions such as ice breaking can resuspend contaminated bed sediments, causing pulses of metals in surface water (Johns and Moore, 1985).

Episodic pulse exposures to toxicants may have more severe impacts on fish than continuous exposures (Ingersoll and Winner, 1982; Seim et al., 1984; Pascoe and Shazil, 1986; Siddens et al., 1986). For example, developing steelhead trout intermittently exposed to copper had lower survival and growth rates and accumulated more copper than fish continuously exposed to copper (Seim et al., 1984). A laboratory study conducted by Pascoe and Shazili (1986) demonstrated that the initial toxic effects of brief cadmium exposures were irreversible. Intermittent pulses of metals, even if relatively infrequent, may thus act as a "bottleneck" on the viability of trout populations in the Clark Fork River.

In order to confirm, under controlled laboratory conditions, whether "pulses" of the hazardous substances copper, cadmium, zinc, and lead similar to those known to occur in the Clark Fork River are lethal to trout, a laboratory study was conducted in which brown and rainbow trout were exposed to concentrations of hazardous substances representative of conditions observed in the Clark Fork River during fish kills (Appendix B[3] describes, in detail, the objectives, methods, results, and conclusions of this laboratory study).

Hatchery stocks of brown and rainbow trout, as well as a wild stock of brown trout raised from free-ranging fish collected from the Clark Fork River (near Warm Springs), were used to test the acute toxicity of hazardous substance pulses. Acute pulse tests were conducted in which concentrations of hazardous substances were gradually increased, held constant, and then decreased over an eight-hour period. Six separate tests were conducted in which trout fry were exposed to pulses of metals. Each test was conducted using hatchery brown and rainbow trout. Clark Fork River brown trout were exposed in two of the six tests. Five different combinations of hardness and pH were used during the pulse exposures (one combination was used twice). In each test, trout were exposed to a mixture of hazardous substances similar to concentrations measured in the Clark Fork during storms and "redwater" events (Table 6-3). The nominal pulse concentrations, defined as the "1P" metals concentration, were 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. The trout in each test were exposed to 1P, 2P, 4P, and 8P metals concentrations, with control trout being exposed to 0P (no metals). Thus, the highest nominal concentrations of metals to which the fish were exposed (8P) was 1,840 ppb zinc, 960 ppb copper, 25.6 ppb lead, and 16.0 ppb cadmium.

[3] "Research Report on Injury Determination, Fishery Protocol #3," by H.L. Bergman.

Table 6-3
Metal Concentrations Measured in the Upper Clark Fork River (CFR), Montana During Storm "Pulse" Events, "Redwater" Spill Events, and Fish Kills (concentrations in µg/l (ppb) total recoverable unless otherwise noted)

Date	Sample Collection Location	Event	Metal Concentration (µg/L)			
			Zn	Cu	Pb	Cd
March 10, 1960[a]	CFR below Warm Springs Ponds	redwater	--	9,000	--	--
	CFR above East Missoula	redwater	--	3,100	--	--
May 1, 1968	CFR between Garrison and Deer Lodge	redwater	4.3	620	--	--
November 20, 1968	CFR Near Warm Springs	redwater	32,500	4,000	--	--
April 10, 1969	CFR at Deer Lodge	redwater	3,600	1,100	--	--
March 1, 1972	CFR near Warm Springs	redwater	500	820	--	--
May 27, 1988[b]	Mill-Willow Bypass	storm event	3,250	2,480	--	--
July 12, 1989[b]	Mill-Willow Bypass	storm event	14,000	13,300	30	85
	CFR below Warm Springs		800	450	10	6
	CFR at Perkins Lane		120	180	4	3
	CFR near Galen		210	370	2	3
	CFR at Deer Lodge (total recoverable)		560	330	15	3
	(dissolved)		230	120	< 1	2
July 2, 1990[b]	Mill-Willow Bypass	storm event	10,300	5,800	--	--

a Water samples collected in association with mortality to caged fish placed instream; no dead native fish observed.
b Water samples collected and analyzed in association with a documented fish kill (see Table 6-1).

Source: Appendix B.

In each of the six tests, the water was brought to full pulse conditions (i.e., peak/target levels of metals, hardness, and pH) over a one hour period. The fish then were exposed to the full pulse conditions for a total of six hours. The water was then returned to initial conditions over another one hour period. Thus, these pulses were "1-6-1" pulses, where the first "1" represents the time (hours) to reach pulse conditions, the "6" represents the duration (hours) of the pulse conditions, and the second "1" represents the time (hours) to return to initial conditions. After the pulses, the trout were monitored for 96 hours, with mortality recorded twice daily.

Similar tests were conducted to compare the relative sensitivity of hatchery brown and rainbow trout fry and juveniles (juveniles are larger than fry[4]) to hazardous substance pulses. These tests differed from the six fry-only tests in that 1) Clark Fork brown trout juveniles were unavailable and hence were not tested, 2) juveniles were tested using a 2-4-2 pulse, and 3) only one combination of hardness and pH was employed (initial hardness = 200 ppm, pulse hardness 100 ppm; initial pH = 7.2 - 8.0, pulse pH = 4.5).

As described in Appendix B, survival of both brown and rainbow trout was significantly reduced ($\alpha = 0.05$)) when trout were exposed to concentrations of Cd, Cu, Pb, and Zn at concentrations similar to those measured in the Clark Fork River (Table 6-4; Figures 6-3a to 6-3f). Exposures as low as 1P caused significant mortality in rainbow trout, exposures as low as 2P caused significant mortality in hatchery brown trout, and exposures as low as 4P caused significant mortality in Clark Fork River brown trout (as noted in Appendix B, the difference in the sensitivity of hatchery and Clark Fork River brown trout most likely is a function of the greater size of the Clark Fork River fish at the time of testing).

Table 6-5 presents mortality statistics using the measured copper and zinc concentrations (rather than the nominal "P" concentrations) for the pulse studies numbers I through V. Reported in the table are the following mortality statistics for hatchery brown and rainbow trout fry:

- LC_{50}.[5] This is the concentration found to cause 50% mortality in the test.

- LC_{20}.[5] The concentration found to cause 20% mortality.

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[4] Juveniles had a mean weight of 21.2 g and a mean length of 126.5 mm. Fry had a mean weight of 0.18 g and a mean length of 28.6 mm (Appendix B).

[5] LC_n concentrations computed using probit model (Finney, 1971). Probit analysis was performed using the S^+ GLM function (Statistical Sciences, Inc., 1993), in which multiple observations of either zero or 100% were trimmed, and empirical survival probabilities were transferred per McCullagh and Nelder (1983).

Table 6-4

Lowest Nominal Concentrations of Hazardous Substances that Caused Significant Mortality During an Eight-Hour Pulse Exposure. *n*P refers to the proportional levels of the hazardous substances where significant mortality ($\alpha = 0.05$) occurred. Numbers in parentheses refer to the percent mortality of the trout in each respective test at the end of the 96-hr observation period.

	Hardness (ppm as $CaCO_3$)		pH				
	Initial	Pulse	Initial	Pulse	Hatchery Brown Trout	Hatchery Rainbow Trout	Clark Fork Brown Trout
Test I	100	100	7.2 - 8.0	7.2 - 8.0	4P, 8P (73, 100)	4P, 8P (37, 100)	
Test II	100	50	7.2 - 8.0	7.2 - 8.0	2P, 4P, 8P (82, 100, 100)	1P, 2P, 4P, 8P (9, 100, 100, 100)	
Test III	100	50	7.2 - 8.0	4.5	4P, 8P (90, 100)	1P, 2P, 4P, 8P (27, 90, 100, 100)	
Test IV	200	100	7.2 - 8.0	4.5	4P, 8P (30, 100)	1P, 2P, 4P, 8P (8, 68, 100, 100)	4P, 8P (27, 100)
Test V	200	100	7.2 - 8.0	4.5	4P, 8P (73, 100)	2P, 4P, 8P (33, 100, 100)	8P (92)
Test VI	200	400	7.2 - 8.0	4.5	no significant mortality	8P (38)	

Note: Nominal "1P" hazardous substance concentrations were as follows: 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Hardness and pH were varied for each test; "initial" refers to the respective levels before and after the pulse event, and "pulse" refers to the respective levels during the pulse event.

Source: Appendix B.

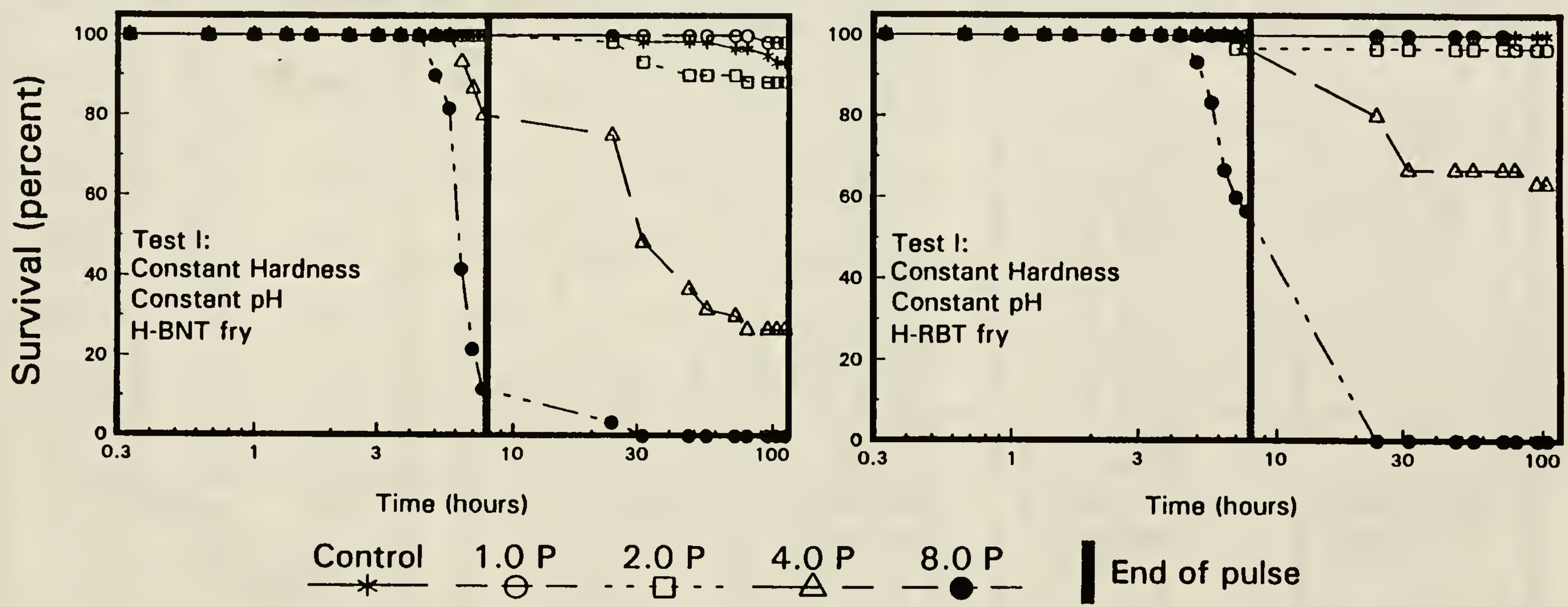

Figure 6-3a. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Test conditions shown in Table 6-4. Source: Appendix B.

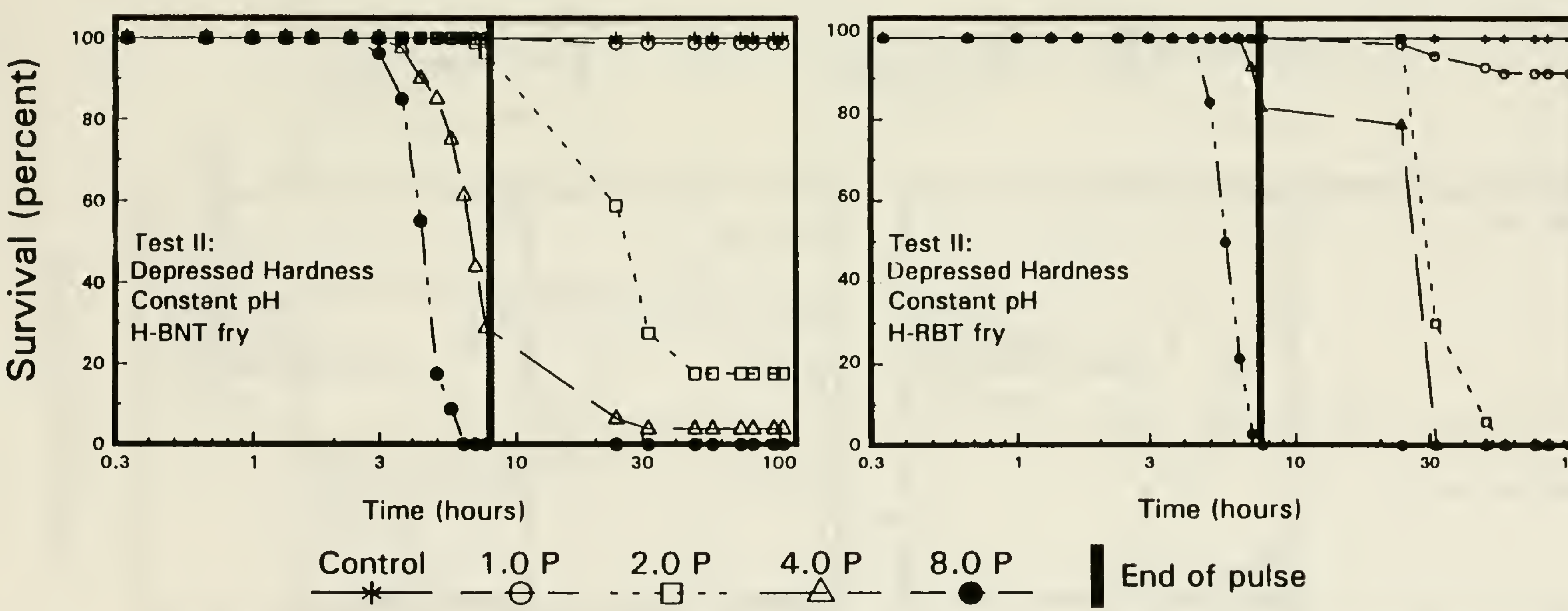

Figure 6-3b. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Test conditions shown in Table 6-4. Source: Appendix B.

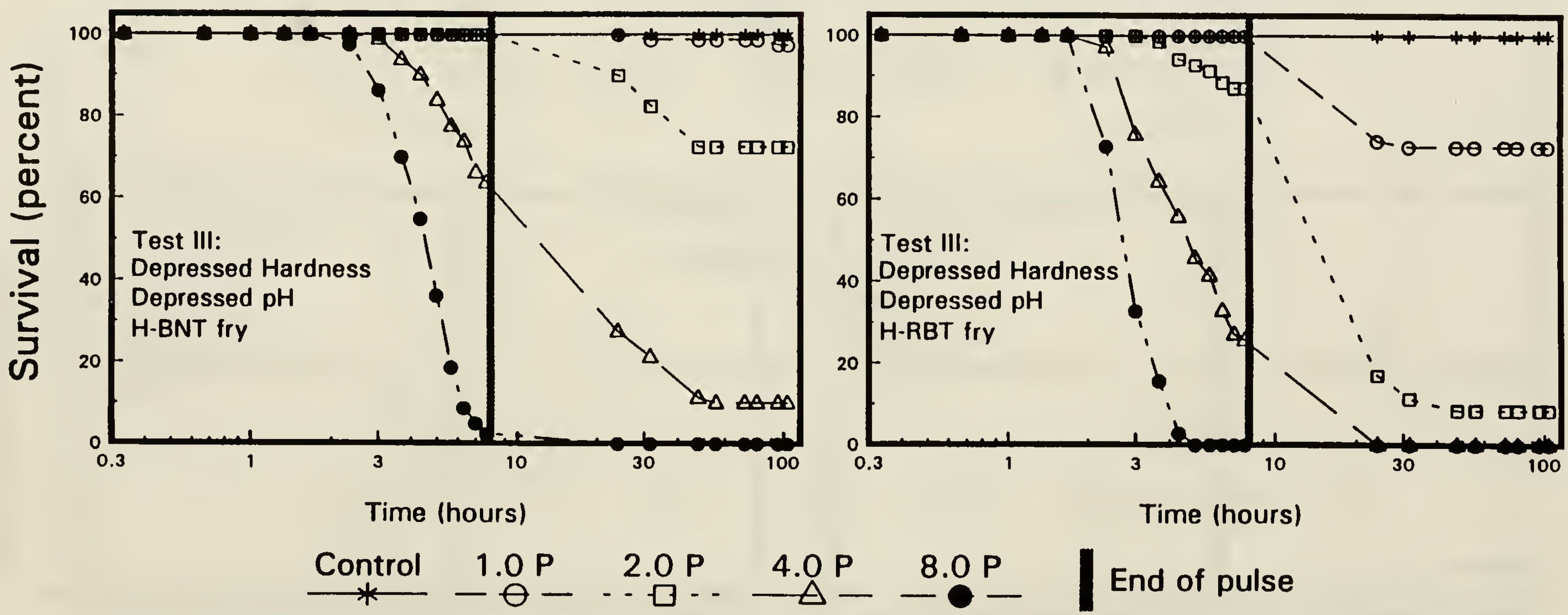

Figure 6-3c. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

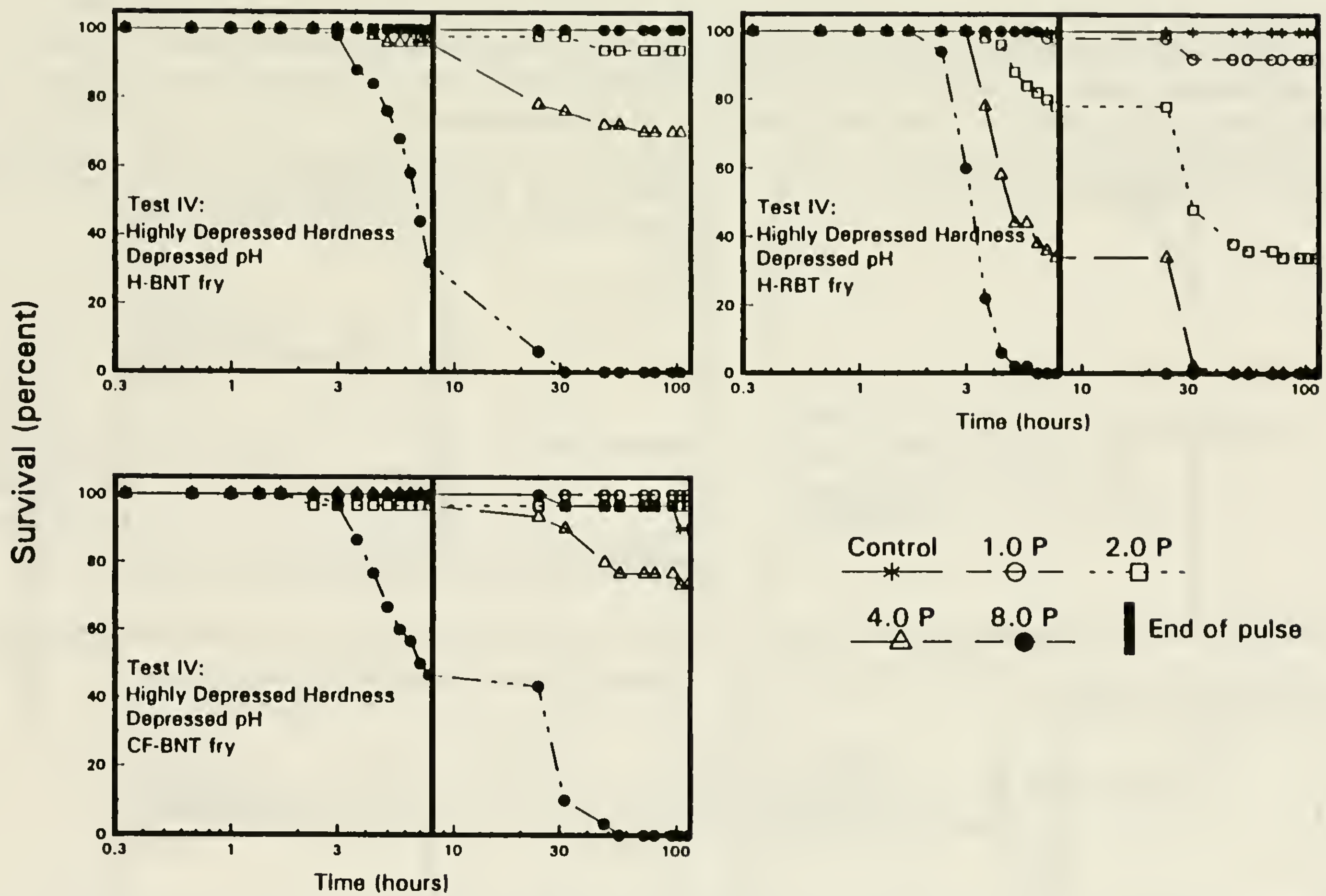

Figure 6-3d. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) and Clark Fork Brown Trout (CF-BNT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

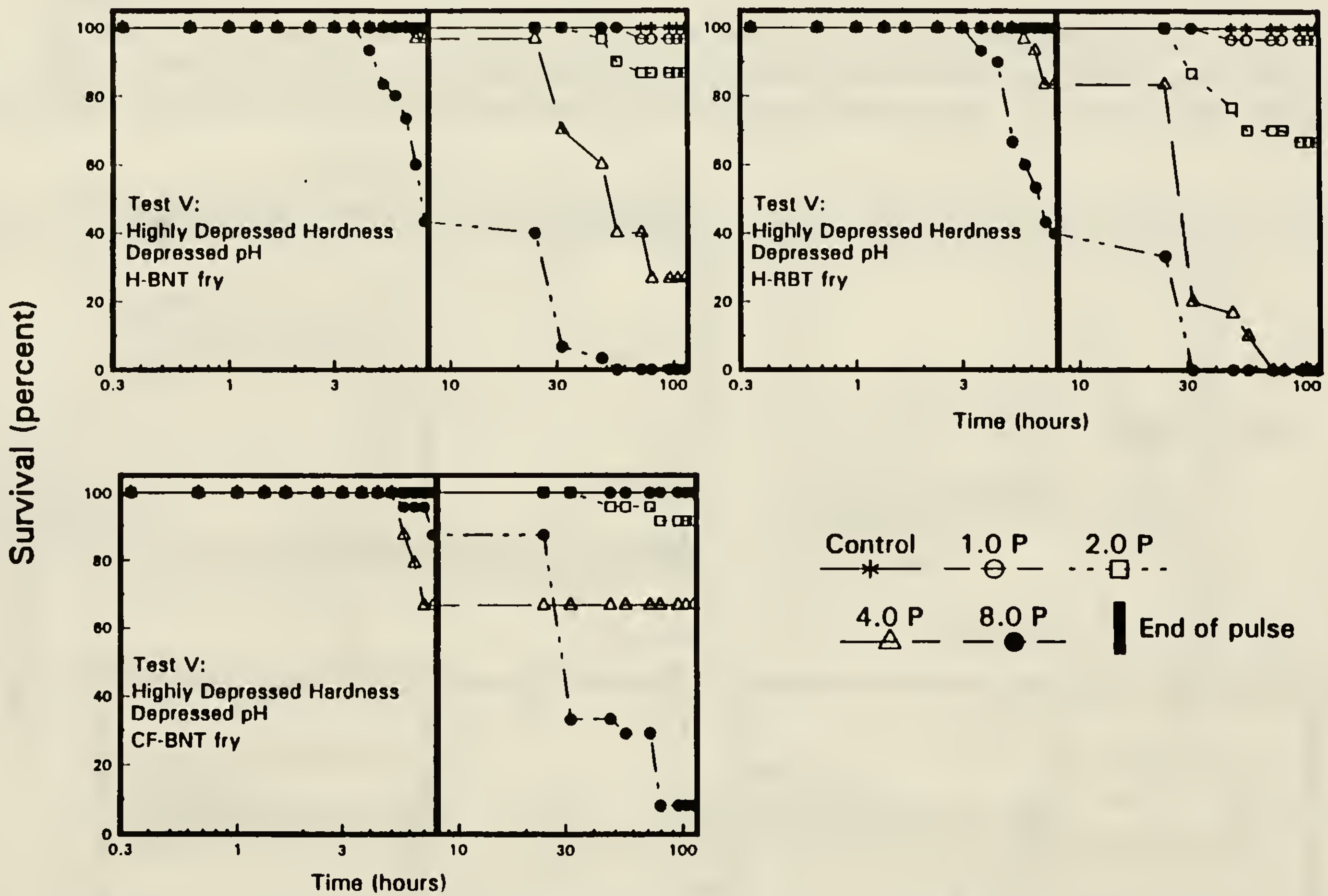

Figure 6-3e. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) and Clark Fork Brown Trout (CF-BNT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

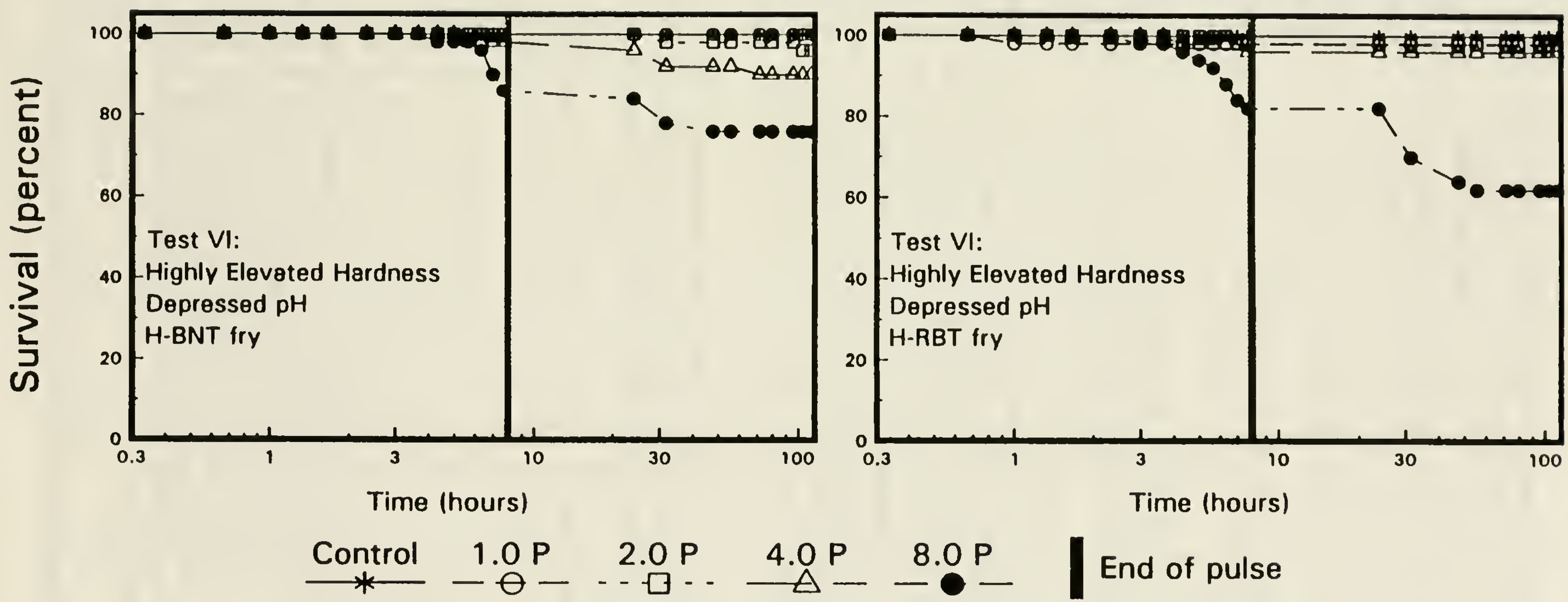

Figure 6-3f. Cumulative Survival of Hatchery-Reared Brown (H-BNT) and Rainbow Trout (H-RBT) Fry During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event. "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Source: Appendix B.

Table 6-5
Pulse Mortality Summary Data
(based on concentrations (µg/l) measured during the laboratory testing)

Test	Species	LC_{50}		LC_{20}		LC_{10}		NOEC		LOEC		MATC	
		Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn
I	Brown Trout	491	1,060	300	658	*	*	285	628	601	1,295	393	902
	Rainbow Trout	668	1,420	471	1,017	368	806	285	628	601	1,295	393	902
II	Brown Trout	265	489	220	408	196	366	149	283	315	577	217	404
	Rainbow Trout	206	384	160	303	137	261	< 149+	< 283+	149	283	**	**
III	Brown Trout	489	770	362	530	295	404	186	271	404	566	274	391
	Rainbow Trout	260	371	168	246	121	180	< 186+	< 271+	186	271	**	**
IV	Brown Trout	789	1,323	599	992	500	819	361	569	708	1,186	505	822
	Rainbow Trout	322	504	247	378	208	312	< 201+	< 300+	201	300	**	**
V	Brown Trout	637	892	454	624	*	*	424	552	763	1,086	569	774
	Rainbow Trout	465	619	354	470	296	393	187	276	424	552	282	391

* Calculated value < NOEC.
** MATC cannot be calculated because no NOEC observed.
\+ Significant mortality at lowest exposure tested.

- LC_{10}.[5] The concentration found to cause 10% mortality. If the LC_{10} was lower than the lowest concentration at which statistically significant mortality occurred, it was deemed an inappropriate statistic.

- LOEC. The lowest concentration at which statistically significant mortality was observed.

- NOEC. The highest concentration at which no statistically significant mortality occurred.

- MATC. The "maximum allowable toxicant concentration." This value, calculated as the geometric mean of the LOEC and the NOEC, often is used as a regulatory effects level (Suter et al., 1987).

Table 6-5 demonstrates that significant trout mortality occurs at metals concentrations lower than those measured in the Clark Fork River during pulse events. For example, copper and zinc concentrations measured during the July 12, 1989 fish kill exceed 13,000 and 14,000 µg/L, respectively, in the Mill-Willow Bypass, and 450 and 800 µg/L in the Clark Fork River downstream of Warm Springs (as shown in Table 6-3).[6] Calculated LC_{10} values (equivalent to 10% mortality) were as low as 121 and 180 µg/L of copper and zinc, respectively, for rainbow trout (Test III) and 196 and 366 µg/l of copper and zinc, respectively, for brown trout (Test II). Even LC_{50} values (50% mortality) were less than concentrations measured in the Clark Fork River.

Overall, the results of this study demonstrate that the pulses of metals that occur in the Clark Fork River and have been associated with fish kills cause trout mortality in controlled laboratory studies. The pulse exposure studies further demonstrated that:

- Significant mortality (relative to the control exposure) was observed in both brown and rainbow trout fry when exposed to the pulses of hazardous substances.

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[6] The water quality data presented in Table 6-3 are based on "total recoverable" concentrations, whereas the data from the laboratory experiments are "dissolved" concentrations. Total recoverable concentrations are greater than dissolved concentrations in field conditions; therefore, dissolved metal concentrations in the Clark Fork River during pulses shown in Table 6-3 likely were lower than the total recoverable concentrations shown. However, for simplicity, the ratio of dissolved: total zinc and copper measured on July 12, 1989 at Deer Lodge, 0.41 and 0.36, can be used as a simplifying approximation of dissolved concentrations reported at the other sampling sites/dates. This comparison demonstrates that dissolved copper and zinc concentrations were substantially greater than those found to cause significant lethality in the laboratory pulse studies.

- Concentrations of hazardous substances similar to those observed in the Clark Fork River during pulse events caused significant mortality in both trout species. Acute mortality was exacerbated when either hardness or pH decreased during the exposure. As described in Appendix B, the results of this study are consistent with the scientific literature.

- Rainbow trout fry were more sensitive (i.e., higher mortality) than brown fry trout to pulses in which pH and hardness were reduced. This may explain, in part, the absence of rainbow trout in the upper portion of the Clark Fork River.

- Mortality was observed as early as three hours after the start of the pulse, and continued for up to 96 hours after the pulse.

Additional tests were performed in order to assess the relative sensitivity of fry and juvenile trout. As shown in Table 6-6 and Figures 6-4a and 6-4b, rainbow trout fry and juveniles had similar sensitivity to metal pulses. Brown trout juveniles, however, were more resistant to the metals pulses than were brown trout fry. This result indicates that pulse-induced fish kills would be expected to affect small fish to a greater extent than larger fish. Such fish kills probably go unnoticed, however, because small fish are less likely to be observed.

Conclusions

Data from the pulse exposure testing demonstrated that:

- "Pulses" of hazardous substances simulating conditions in the Clark Fork River during fish kills caused acute mortality to both brown and rainbow trout in laboratory exposures.

- Significant mortality was found in both fry and juvenile rainbow and brown trout.

- When hardness was decreased during the pulse exposures (as has been documented in the Clark Fork River),[7] mortality was significantly greater than when hardness was held constant.

- Rainbow trout were more sensitive to pulse exposures than brown trout when pH and hardness were decreased.

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[7] For example, see Appendix B and Table 6-7, below.

Table 6-6
Nominal Concentrations of Hazardous Substances that Caused Significant Mortality During an Eight-Hour Pulse Exposure.
***n*P refers to the proportional levels of the above hazardous substances where significant mortality ($\alpha = 0.05$) occurred. Numbers in parentheses refer to the percent mortality of the trout in each respective test at the end of the 96-hour observation period.**

Hardness (ppm as $CaCO_3$)		pH		Brown Trout Fry	Brown Trout Juveniles	Rainbow Trout Fry	Rainbow Trout Juveniles
Initial	**Pulse**	**Initial**	**Pulse**				
200	100	7.2 - 8.0	4.5	4P, 8P (45, 85)	8P (40)	4P, 8P (80, 100)	4P, 8P (95, 100)

Note: Nominal "1P" hazardous substance concentrations were as follows: 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Hardness and pH were varied for each test; "initial" refers to the respective levels before and after the pulse event, and "pulse" refers to the respective levels during the pulse event.

Source: Appendix B.

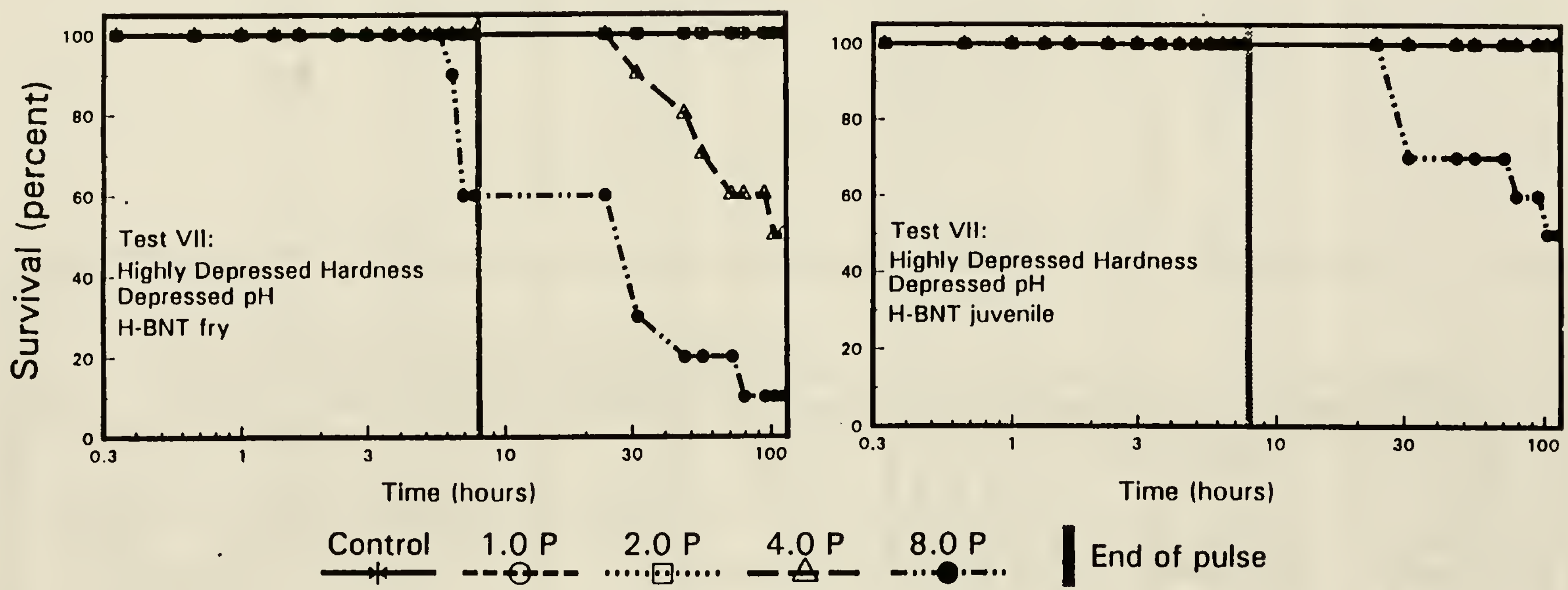

Figure 6-4a. Cumulative Survival of Hatchery-Reared Brown Trout (H-BNT) Fry and Juveniles During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event (First Replicate). "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium.

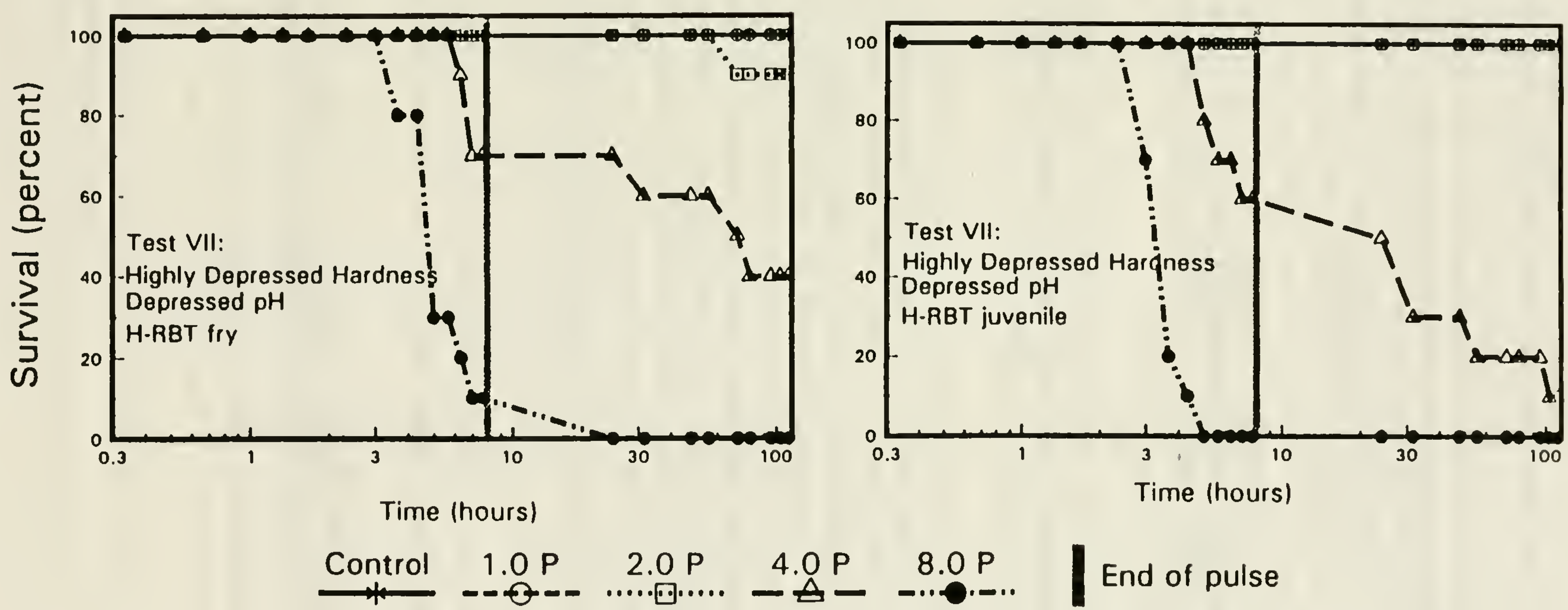

Figure 6-4b. Cumulative Survival of Hatchery-Reared Rainbow Trout Fry (H-RBT) and Juveniles During an Eight-Hour Pulse Event and for 96 Hours Following the Pulse Event (First Replicate). "1P" is a metals concentrations of 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium.

- Clark Fork River brown trout had similar sensitivity to pulse exposures as did hatchery brown trout in one test, and were more tolerant than hatchery brown trout in a second replicate test. However, differences in tolerances between brown trout strains likely were caused by size differences at the time of testing.

- In general, the order of species/size sensitivity to pulses was rainbow trout fry ≈ rainbow trout juveniles > brown trout fry > brown trout juveniles.

In most cases, the rainbow trout fry were more sensitive to the pulses than were the brown trout fry. This result is consistent with the absence of rainbow trout in the upper reaches of the Clark Fork River. In addition, the pulse tests demonstrated that brown trout fry are more sensitive to pulses than are brown trout juveniles.

Because runoff pulse events usually are associated with turbid water, and because trout fry are very small (and hence are not readily observed), fish kills involving trout fry are likely to have occurred far more often than the documented kills of much larger fish.

Results of pulse tests showed that reductions in hardness and pH resulted in an increase in the toxicity of metals to trout. During many of the high runoff events recorded in the Clark Fork River, hazardous substance concentrations increased while hardness and pH decreased. For example, Table 6-7 presents water quality conditions measured during the May 27, 1988 fish kill. Measured copper and zinc concentrations near the beginning of the pulse were as high as 2,480 µg/l and 3,250 µg/l, respectively (20 and 14 times the "P" concentrations). Both pH and hardness also decreased during this pulse. Moreover, as shown by the concentrations of copper and zinc in tailings runoff during two storm events (over 1,000 times the "P" concentrations), these measured instream concentrations (with downstream dilution) likely do not represent the maximum pulse concentrations that would occur directly downstream of tailings runoff. Overall, the results of the pulse experiments clearly support the conclusion that pulses of hazardous substances are responsible for acute trout mortality in the Clark Fork River.

6.4.5 Category of Injury: Death/Acute Lethality from Exposure to Hazardous Substances

In a separate study (Appendix C[8]), hatchery-reared brown and rainbow trout, as well as Clark Fork River brown trout, were exposed to various concentrations of hazardous substances

[8] "Research Report on Injury Determination, Fishery Protocol #5," by H.L. Bergman.

Table 6-7
Concentrations of Copper, Zinc, and Ancillary Water Parameters in Mill-Willow Bypass, the Clark Fork River, and Tailings Runoff During May 27, 1988 Fish Kill
(Also shown are copper and zinc concentrations as multiples of the nominal "p" concentrations used in the pulse studies. Concentrations as low as 1p were found to cause significant trout mortality.)

Location	Time	pH	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Copper (µg/l)	Zinc (µg/l)	Copper (xP)	Zinc (xP)
Mill-Willow Bypass near Hog Hole[1]	3:50 pm	4.79	1.2	160	2,480	3,250	20.7	14.1
Mill-Willow Bypass near Pond 2[1]	4:00 pm	5.52	7.8	164	1,800	2,460	15.0	10.7
Clark Fork River below Warm Springs Creek bridge[1]	4:30 pm	7.24	61.0	133	70	120	0.6	0.5
Mill-Willow Bypass near Pond 2[1]	5:15 pm	7.18	38.0	112	280	320	2.3	1.4
Mill-Willow Bypass near Pond 2[1]	6:10 pm	7.25	45.0	109	100	90	0.8	0.4
Tailings runoff[2]	NA	NA	NA	NA	640,000	NA	5,333	NA
Tailings runoff[3]	NA	NA	NA	NA	217,500	273,000	1,813	1,187

1 MDHES and CH_2M Hill, 1989.
2 Concentration measured in simulated storm event runoff from tailings several miles above the Mill-Willow Bypass (MDHES and CH_2M Hill, 1989).
3 Concentrations are averages of those measured in runoff during two storm events: Colorado Tailings (July 8, 1986) and Ramsay Flats (July 16, 1986).

(cadmium, copper, lead, and zinc), representative of conditions that are found in Silver Bow Creek and the Clark Fork River. The objectives of this study were to assess whether:

1. Continuous short-term exposure to metals concentrations observed in Clark Fork River are acutely lethal to brown and rainbow trout.

2. Clark Fork River brown trout are genetically adapted to tolerate elevated concentrations of metals.

6.4.5.1 Determination of Acutely Lethal Concentrations

As described in Appendix C, hatchery-reared brown and rainbow trout juveniles and fry[9] as well as brown trout juveniles collected from the Warm Springs area of the Clark Fork River, were exposed to water containing zinc, copper, lead, and cadmium to assess mortality. Trout were exposed to concentrations of 5P, 2.5P, 1.2P, 0.6P, and 0.3P, where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Thus, the fish were exposed to nominal metals concentrations ranging from 69 ppb zinc, 36 ppb copper, 1.0 ppb lead, and 0.6 ppb cadmium (0.3P dilution), to 1,150 ppb zinc, 600 ppb copper, 16 ppb lead, and 10 ppb cadmium (5P dilution). Mortality was monitored during each test (Figure 6-5) and LC_{50}s, the concentrations which caused mortality in 50% of the test organisms, were calculated (Table 6-8 and Figure 6-6).

At both the 48- and 96-hour interval, rainbow trout had significantly higher LC_{50}s (i.e., were less sensitive) than either Clark Fork or hatchery brown trout. At 48 hours, the LC_{50}s for the two brown trout categories were not significantly different. However, after 96 hours, Clark Fork brown trout had a significantly lower LC_{50} (i.e., were more sensitive) than the hatchery brown trout. Thus, at 96 hours, rainbow trout were less sensitive to hazardous substances in continuous exposures than brown trout.

Similar acute lethality tests were performed using hatchery rainbow and brown trout fry (i.e., smaller than juvenile trout). Figure 6-7, which describes the cumulative percent survival of fry in these tests, demonstrates that roughly 20% mortality was observed in the brown trout fry at the lowest concentration tested (0.3P), with 100% mortality at all higher concentrations. Rainbow trout fry demonstrated roughly 10% mortality in the 0.3P exposure; mortality was 100% at all higher concentrations.

Table 6-8 presents summary statistics from these acute lethality tests. Again, data are shown for the LC_{50}, LC_{20}, and LC_{10} values, as well as LOEC, NOEC, and MATCs. Concentrations of the magnitude observed in Table 6-8 have been documented regularly in Silver Bow Creek and the Clark Fork River (see Chapter 4.0 - Surface Water). For example, even the 96-hour LC_{50} values for brown trout fry, equivalent to roughly 65 µg/l copper and 100 µg/l zinc (Table 6-8), fall within the range of metals concentrations documented in Silver Bow Creek and the Clark Fork River. LC_{20}, LC_{10}, and MATC values are lower than the LC_{50} values. Again, similar concentrations have been observed in the Clark Fork River. In addition, Table 6-8 demonstrates the greater sensitivity of trout fry to metals relative to juveniles. For example, the calculated LC_{20} for rainbow trout fry (52 µg/l copper) was roughly 45% lower than the corresponding LC_{20} for rainbow trout juveniles. A similar pattern was observed in brown trout.

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[9] Fry data not presented in Appendix C. Data are presented in Table 6-8 and Figure 6-7.

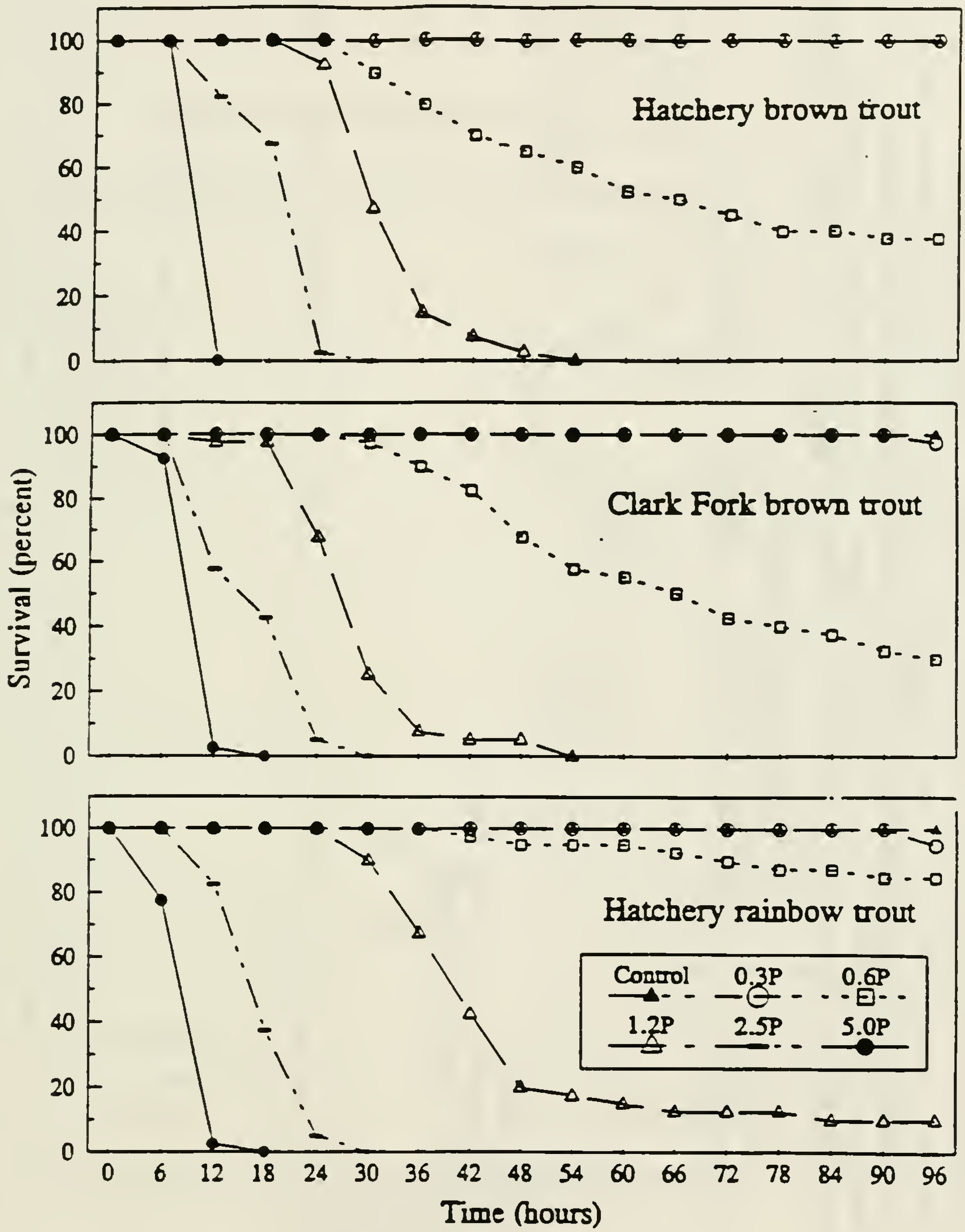


Figure 6-5. **Cumulative Percent Survival for Hatchery Brown Trout, Clark Fork Brown Trout, and Hatchery Rainbow Trout Exposed to "p" Dilutions of Zn, Cu, Pb, and Cd, where 1P = 230 ppb Zn, 120 ppb Cu, 3.2 ppb Pb, and 2.0 ppb Cd.** Source: Appendix C.

Table 6-8
96-Hour Lethality Concentrations (based on measured concentrations, µg/l, in laboratory testing)

Species	LC_{50}		LC_{20}		LC_{10}		NOEC		LOEC		MATC	
	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn
H-RBT-Fry	61	96	52	80	47	72	45	69	92	147	64	101
H-RBT-Juvenile	134	219	94	152	*	*	92	147	180	298	129	209
H-BRT-Juvenile	87	138	72	113	64	100	45	69	92	147	64	101
H-BRT-Fry	65	102	49	76	41	63	< 45+	< 69+	45	69	**	**
CF-BRT-Juvenile	82	130	65	102	55	87	45	69	92	147	64	101

* Calculated value < NOEC.
** MATC cannot be calculated because no NOEC observed.
+ Significant mortality at lowest exposure tested.
H: Hatchery strain.
RBT: Rainbow trout.
BRT: Brown trout.
CF: Clark Fork River strain.

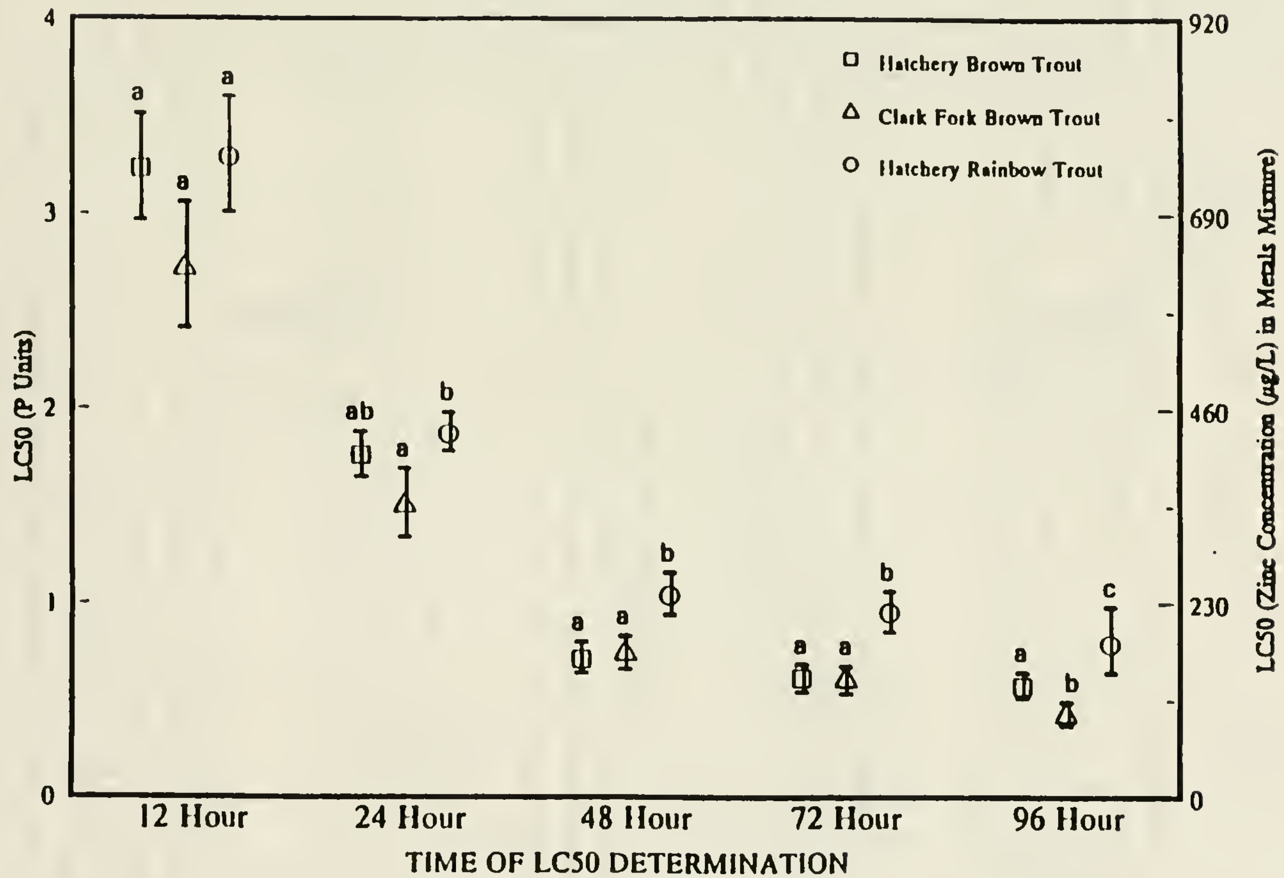
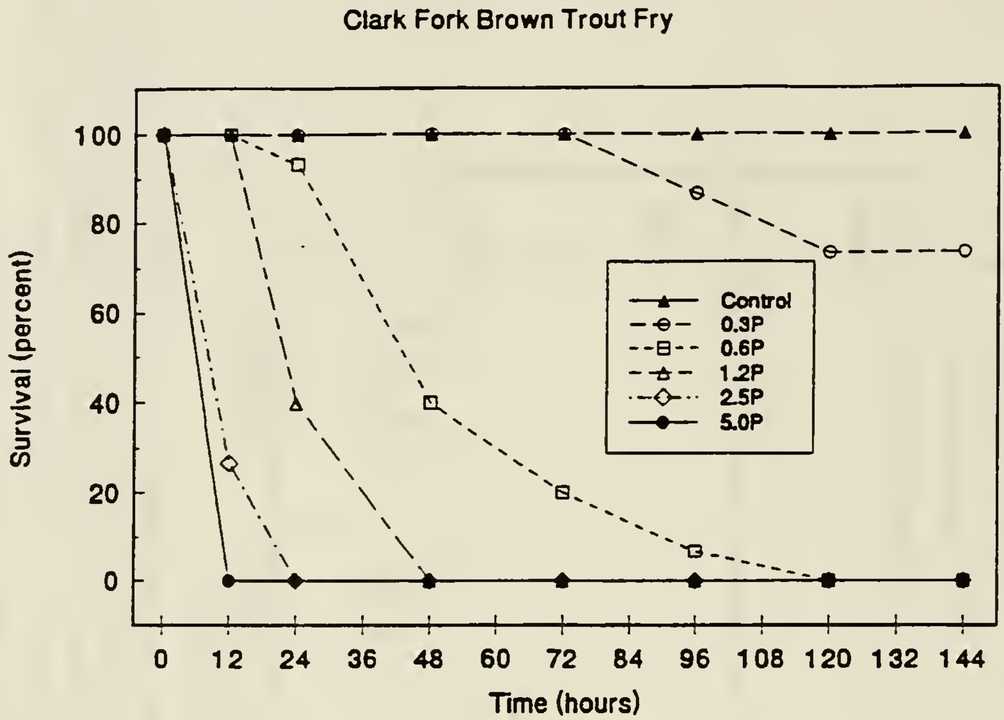


Figure 6-6. **Median Lethal Concentrations (LC_{50}s) and 95% Confidence Intervals at 12- to 96-Hour Intervals for Hatchery Brown and Rainbow Trout and Clark Fork River Brown Trout Exposed to Dilutions of a Mixture of Zinc, Copper, Lead, and Cadmium.** LC_{50}s are in "P Units," or multiples of the 1P concentration, where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. LC_{50} values with the same subscripted letter are not significantly different ($\alpha = 0.05$); those with different letters are significantly different.
Source: Appendix C.



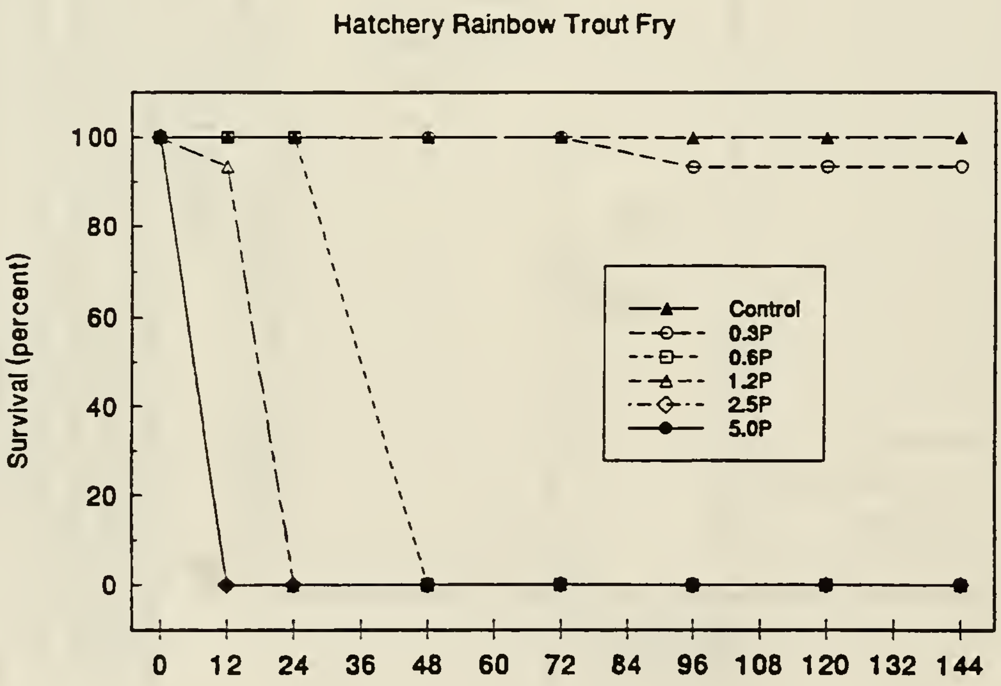


Figure 6-7. **Cumulative Percent Survival for Hatchery Brown Trout and Rainbow Trout Fry Exposed to "p" Dilutions of Cd, Cu, Pb, and Zn.**

Overall, the results of these tests demonstrate that exposure to concentrations of hazardous substances at concentrations observed in Silver Bow Creek and the Clark Fork River causes acute trout mortality, and that smaller trout are more sensitive to hazardous metals than larger trout.

6.4.5.2 Acclimation Studies: Determination of Time to Death

The relative sensitivity to hazardous substances between species/stocks can be ascertained by determining the length of time that organisms can survive in the presence of hazardous substances. Resistance is normally measured as the "mean time to death," or LT_{50}, the time at which 50% mortality in test organisms occurs (Sprague, 1985). This test is useful for determining whether a given species or organism can acclimate to lethal conditions; the longer the organisms survive under the given conditions, the greater the level of acclimation.

In order to assess the ability of rainbow and brown trout (including hatchery and Clark Fork River stocks) to acclimate to — and hence resist — metals concentrations, LT_{50}s were determined following varying periods of acclimation to low levels of hazardous substances (Appendix C). Three separate acclimation tests ("challenges") were performed. First, trout were acclimated for three weeks to nominal concentrations of zinc, copper, lead, and cadmium similar to ambient Clark Fork River conditions. The acclimation metals levels were 0.2P, where 1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium. Thus, the 0.2P level of metals was 46 ppb zinc, 24 ppb copper, 0.6 ppb lead, and 0.4 ppb cadmium. The second acclimation test involved acclimating trout to the 0.2P metals for five weeks. The third test involved acclimating hatchery brown and rainbow trout to the 0.2P metals for six weeks, then returning the fish to control water (0P) for two weeks before beginning the test (Figure 6-8).

In all three tests, the acclimated fish were cold-branded for identification, placed in a test chamber with unacclimated fish (i.e., acclimated only to 0P control water), and exposed to 1P metals concentrations. Mortality was monitored every two hours for the first 12 hours, and every six hours for the remainder of the test. Both LT_{50}s and the mean time to death were calculated.

The results of the three LT_{50} acclimation tests are summarized in Table 6-9 and Figures 6-9 and 6-10. Survival time (i.e., resistance to metals) increased significantly when fish (all species/stocks) were acclimated to low concentrations of metals. Although the results of the three week acclimation test (challenge I) appear to show that Clark Fork brown trout had a greater ability to acclimate to the hazardous substances than either of the hatchery trout species, this result likely occurred because the Clark Fork River trout tested were larger than the corresponding hatchery stock at the time of testing (see Appendix C). After five weeks of acclimation (challenge II), both brown trout stocks evidenced significantly greater resistance to the metals mixture than the rainbow trout; again, the apparent difference between the two brown trout stocks is likely an artifact of the size of the fish tested rather than genetic adaptation (Appendix C).

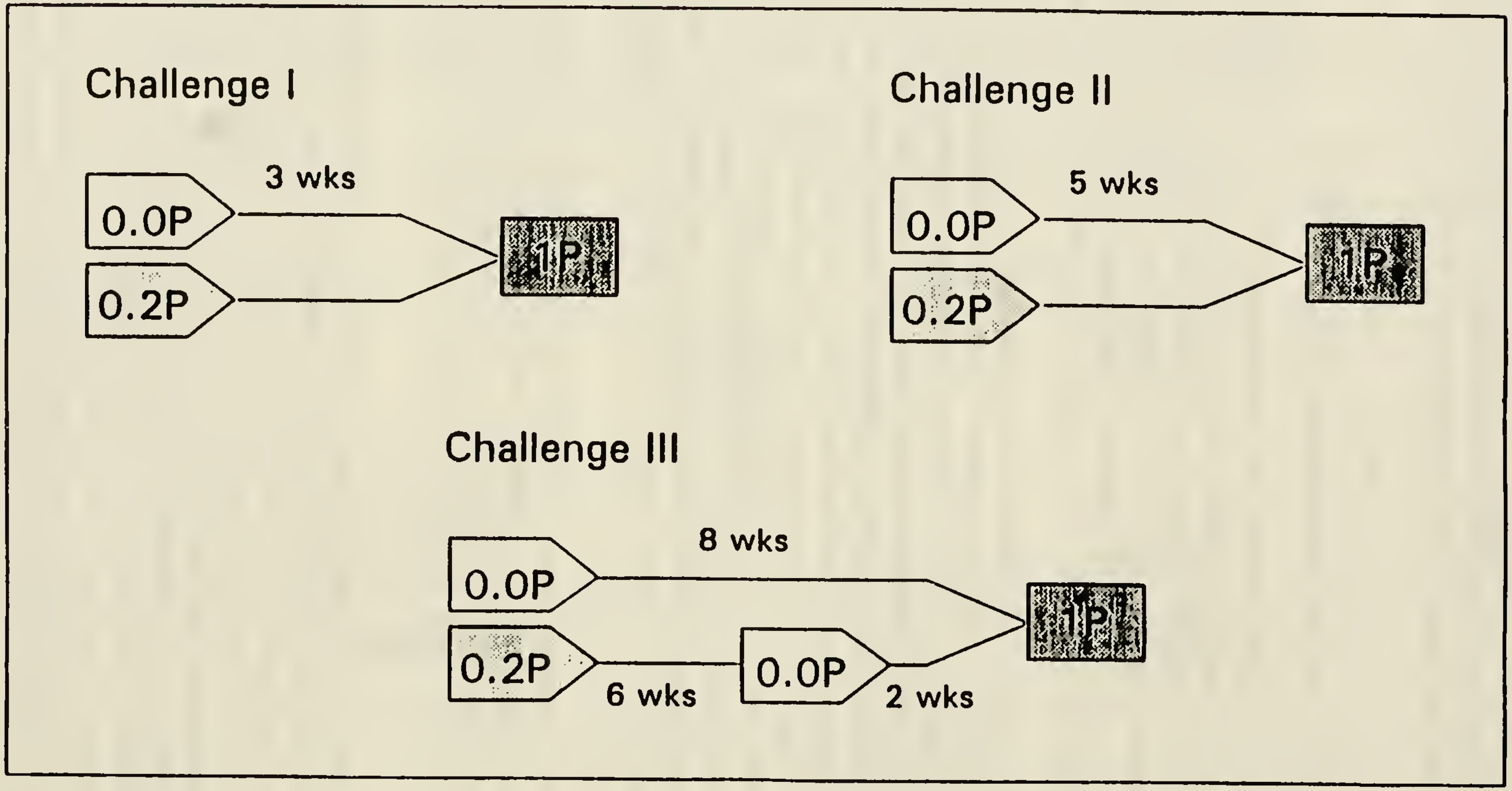


Figure 6-8. Schematic Diagram of Three Experimental Challenges to Determine Time-to-Death. "1P" concentration equal to 230 ppb Zn, 120 ppb Cu, 3.2 ppb Pb, and 2.0 ppb Cd. Source: Appendix C.

Table 6-9
LT_{50} Estimates (hours) for Hatchery Brown and Rainbow Trout and Clark Fork Brown Trout

Test Trout	LT_{50} (hours) (0P control)	LT_{50} (hours) (0.2P acclimated)
3 Weeks Acclimation		
Hatchery brown trout	24.5	39.9
Clark Fork brown trout	26.4	61.4
Hatchery rainbow trout	25.1	36.8
5 Weeks Acclimation		
Hatchery brown trout	29.1	95.7
Clark Fork brown trout	49.5	146.2
Hatchery rainbow trout	29.4	35.8
6 Weeks Acclimation + 2 Weeks De-acclimation		0.2P - 0P
Hatchery brown trout	31.3	19.9
Hatchery rainbow trout	25.8	42.7

Note: The control trout had no metals in acclimation water; test trout were acclimated to a 0.2P metals concentration (46 ppb zinc, 24 ppb copper, 0.6 ppb lead, and 0.4 ppb cadmium) for a designated period of time. After the acclimation period, test and control fish were exposed to 1P metals concentrations (1P = 230 ppb zinc, 120 ppb copper, 3.2 ppb lead, and 2.0 ppb cadmium) until mortality was complete (unless otherwise indicated). Median time to death (LT_{50}) was determined as described in Appendix C.

Source: Appendix C.

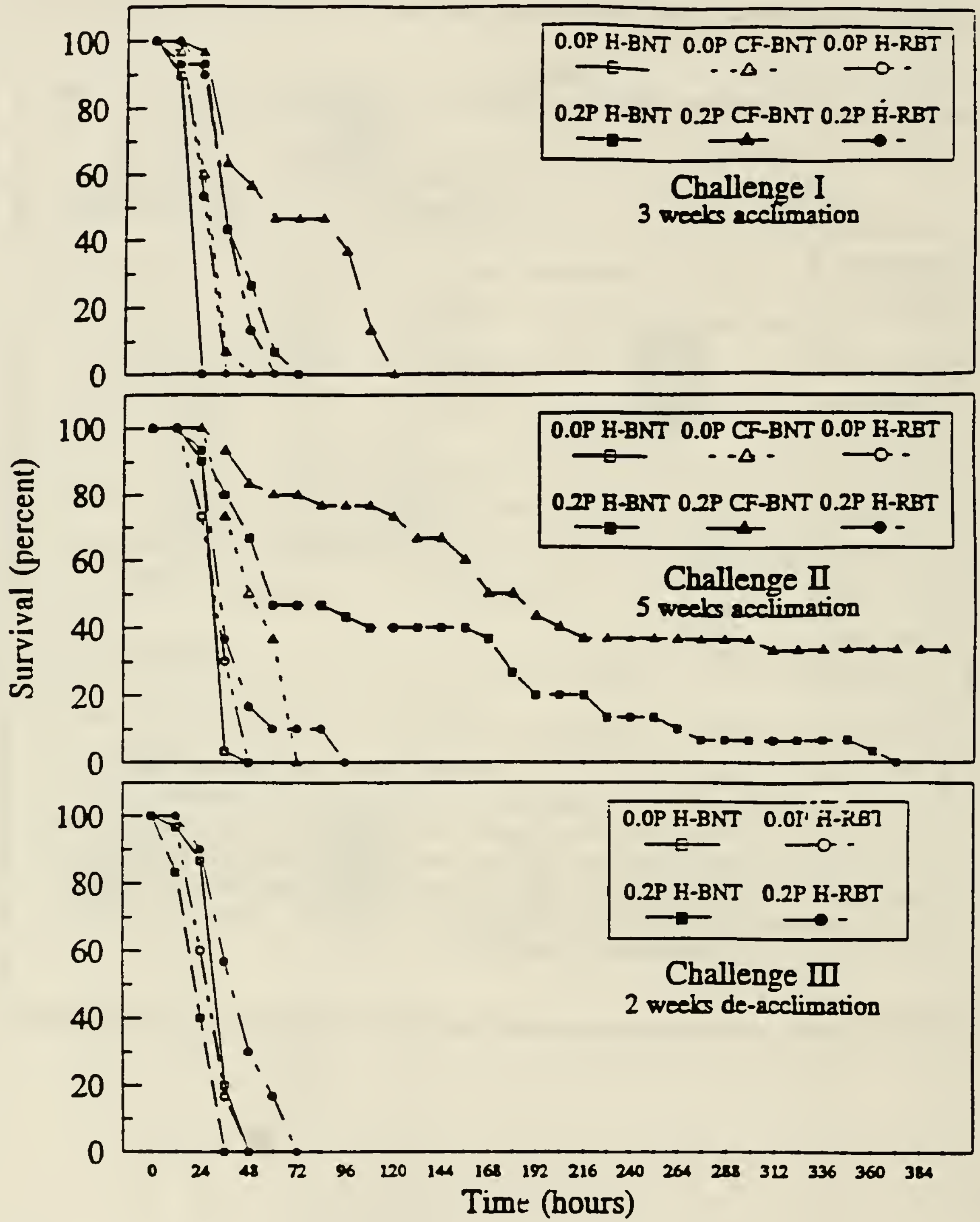


Figure 6-9. **Cumulative Percent Survival During Challenge Periods.** H-BNT = hatchery brown trout, CF-BNT = Clark Fork brown trout, H-RBT = hatchery rainbow trout. Source: Appendix C.

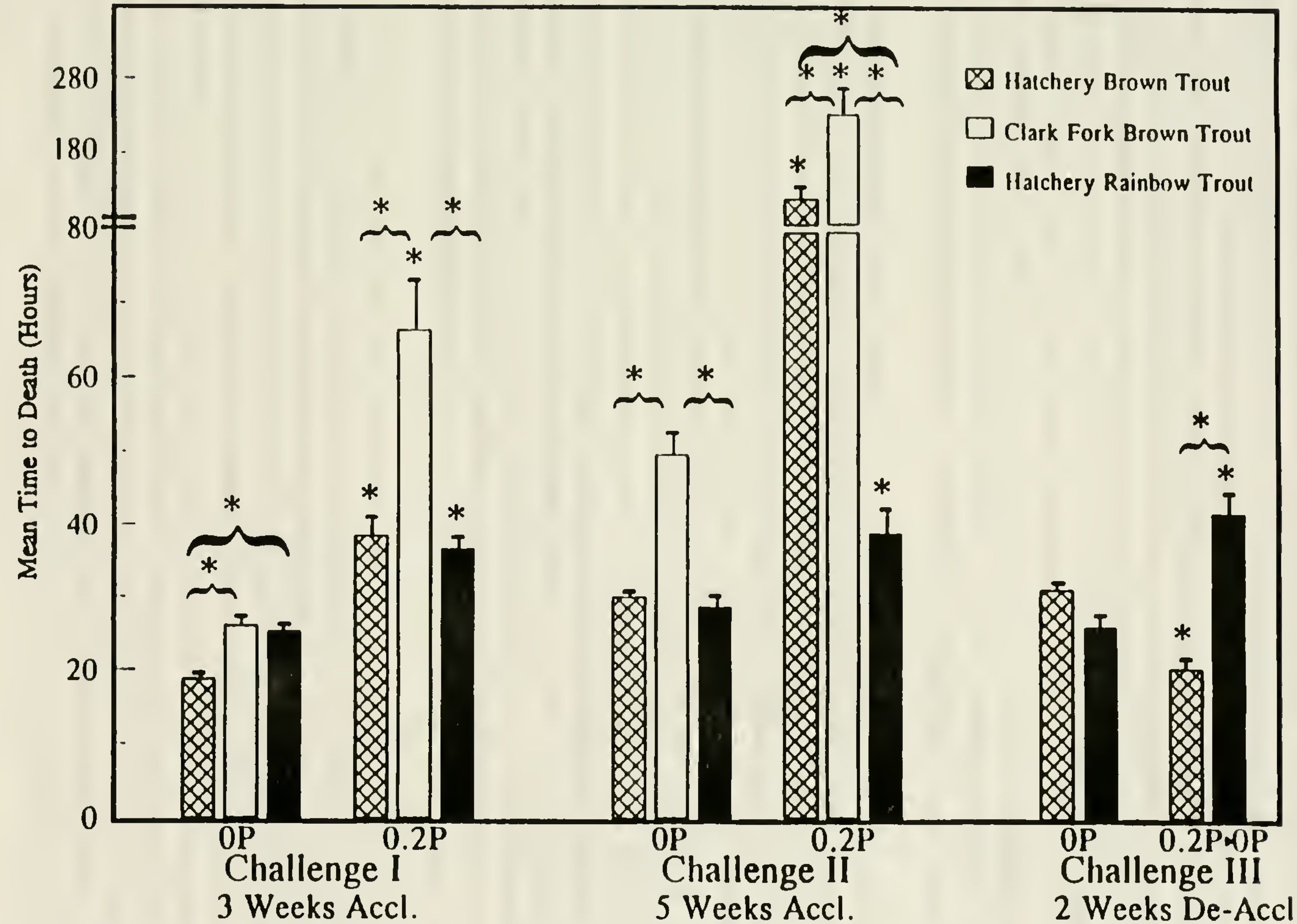


Figure 6-10. Mean (+1 Standard Error of the Mean) Time to Death. Asterisks directly above 0.2P test groups indicate significant difference from the paired 0P group of the same species ($p < 0.05$); an asterisk above a bracket indicates significant difference between the bracketed pair of mean values ($p < 0.05$). Source: Appendix C.

After six weeks of acclimation followed by two weeks de-acclimation in 0P water (challenge III), brown trout that were acclimated and then de-acclimated had a significantly *shorter* LT_{50} than did the control brown trout. (This test was only performed on hatchery trout because of insufficient numbers of Clark Fork River brown trout.) The de-acclimated rainbow trout, on the other hand, had a significantly *longer* LT_{50} than the rainbow trout control, as well as a significantly longer LT_{50} than either the brown trout test or control. This *increased sensitivity* in the de-acclimated fish may reflect the physiological "cost of acclimation." The cost of acclimation has been related to reduced growth in other studies (see Appendix C). The results of the de-acclimated challenge may indicate, however, that fish that have borne the physiological cost of acclimation may be less able to tolerate subsequent metals exposures following a de-acclimation period.

Summary and Conclusions

The results of the acute lethality and acclimation studies support the following conclusions:

- Acute exposure to cadmium, copper, lead, and zinc caused significant mortality to hatchery rainbow and brown trout, as well as Clark Fork River brown trout, at concentrations frequently observed in the Clark Fork River and Silver Bow Creek. Small trout (fry) were more sensitive than larger trout (juveniles).

- Prior to acclimation, the order of sensitivity to metals was found to be Clark Fork River brown trout > hatchery brown trout > rainbow trout.

- All three species/stocks demonstrated increased resistance to metals following acclimation to low levels of metals, with the order of sensitivity being reversed post-acclimation: rainbow trout > hatchery brown trout ≈ Clark Fork River brown trout. This ability to acclimate may help explain the presence of brown trout in the Clark Fork River (although at greatly reduced numbers relative to baseline conditions).

In addition to the above conclusions, it is important to note that reduced growth has been identified as an effect of sublethal metal exposures (see Sections 6.4.7 and 6.4.8). As described in Appendix C, acclimation to metals involves a metabolic "cost" to fish; this metabolic cost has been associated with reduced growth in the scientific literature. These conclusions are consistent with the pattern of reduced growth that was observed in laboratory feeding studies. Hence, the ability to acclimate to metals may afford a somewhat enhanced ability to resist metals exposures over the short term. However, over the long term, the metabolic costs associated with structural, physiological, and biochemical resistance to metals cause growth reductions that ultimately reduce an organism's ability to survive in the wild.

6.4.5.3 Category of Injury: Death Comparison of Relative Sensitivity of Brown and Rainbow Trout

As described previously, rainbow trout rarely occur in the Clark Fork River upstream of its confluence with Rock Creek, whereas brown trout are found in these upstream reaches. The results of the lethality studies (coupled with the behavioral avoidance testing — see below at Section 6.4.6) are consistent with this apparent difference in population responses between brown and rainbow trout. The results of the pulse exposure testing demonstrated that when conditions were similar to those observed during pulses (reduced pH, hardness, and alkalinity), rainbow trout were more sensitive to metals than brown trout. Similarly, brown trout had a greater ability to acclimate to sub-lethal metals concentrations and were more resistant to metals than rainbow trout to subsequent lethal exposures. Therefore, both studies demonstrated that brown trout were more tolerant of metals than rainbow trout during conditions similar to actual ambient conditions. This is consistent with the observed absence of rainbow trout in the upper reaches of the Clark Fork River.

6.4.6 Category of Injury: Behavioral Abnormality/Avoidance

Both laboratory and field studies have shown that fish actively avoid harmful environmental conditions. Salmonids (trout and salmon) have been shown to avoid dissolved copper concentrations as low as 0.1 parts per billion (Folmar, 1976). Releases of copper and zinc from a mine drainage into a salmon spawning tributary resulted in 10% to 22% repulsion of ascending salmon in four consecutive years, compared to 1% to 3% repulsion prior to the mine drainage release (Saunders and Sprague, 1967). Avoidance behaviors in the Clark Fork River can impede movement of trout from tributary streams into the Clark Fork River for rearing purposes, and can cause fish in the Clark Fork River to move into tributaries which, themselves, have limited available habitat. Hence, avoidance responses can contribute to reductions in trout populations.

To determine whether brown and rainbow trout avoid, and therefore are injured by, the hazardous substances to which they are exposed in the surface water of the Clark Fork River, controlled laboratory avoidance tests were performed at the National Fisheries Contaminant Research Center Laboratory in Jackson, Wyoming, using simulated Clark Fork River and control water (Appendix D[10]). Following is a brief summary of these laboratory tests.

As described in Chapter 4.0, concentrations of hazardous substances in Clark Fork River water frequently exceed ambient water quality criteria (AWQC) set by the U.S. EPA. The chronic AWQC values (100 ppm hardness as $CaCO_3$) for cadmium, copper, and lead, and 45% of the chronic AWQC for zinc, were used to represent ambient spring conditions in the

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[10] "Jackson Protocol P92-40050-10-02: Avoidance," by D.F. Woodward and H.L. Bergman.

Clark Fork River (equivalent to 1.1 ppb cadmium, 12 ppb copper, 3.2 ppb lead, and 50 ppb zinc). In previous experiments, these concentrations have been determined to be appropriate for simulating Clark Fork River conditions by U.S. EPA, ARCO, and U.S. Fish and Wildlife Service investigators (Environmental Toxicology, 1991; U.S. FWS, 1991).

In the avoidance testing, the above metals concentrations were defined as the "1X" concentration.[11] Brown and rainbow trout were exposed to 0X (control), 0.1X, 0.5X, 1X, 2X, 4X, and 10X concentrations of hazardous substances in a chamber with control water on one side and test water on the other side (see Appendix D). Avoidance responses were assessed by quantifying the amount of time a fish spends in the control water versus the test water containing the hazardous substances.[12]

The results of this testing (Table 6-10; and Figures 6-11 and 6-12) demonstrated that both brown and rainbow trout significantly avoided hazardous substances representative of Clark Fork River conditions (1X metals concentration). Brown trout significantly avoided test waters at concentrations as low as 0.5X. Brown trout demonstrated a slight reduction of the avoidance response at the 4X and 10X concentrations. This impairment of the avoidance response at elevated concentrations is consistent with the scientific literature. For example, Gardner and LaRoche (1973) and Giattina et al. (1982) found that very high concentrations of copper disable or destroy sensory systems leading to decreased avoidance, increased exposure, and mortality.

Rainbow trout were found to demonstrate a greater avoidance "sensitivity" than brown trout (Table 6-10; Figure 6-12), significantly avoiding water with concentrations of hazardous substances as low as 0.1X. Unlike brown trout, rainbow trout did not show indications of decreased avoidance at elevated metals concentrations.

In a separate test, rainbow trout were acclimated to the ambient Clark Fork (1X metals) water for 30 days prior to the avoidance test. During the test, the reference water was 1X instead of 0X, and the test waters were 0X, 1X or 4X metals concentrations. The acclimation had a dramatic effect on the length of time that a rainbow trout would spend in test water. When both test and reference water were at 1X concentrations, rainbow trout spent roughly 50% of the time in the test water. However, when the "test" water contained 0X metals, the rainbow trout again significantly avoided the 1X exposure, spending 84% of the time in the 0X water (Table 6-11). When metals concentrations were higher (4X) than in the reference side, acclimated rainbow trout avoided the 4X exposure 70% of the time. Thus, even rainbow trout acclimated to 1X metals for 30 days showed a strong avoidance response.

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[11] Note that the "1X" concentrations used in this study are different than the "1P" concentrations discussed previously in the pulse studies.

[12] If no avoidance behavior is manifested, fish will spend, on average, 50% of the time in each end of the avoidance apparatus.

Table 6-10
Brown and Rainbow Trout Avoidance Responses to Hazardous Substances in Surface Water
(Reference Water = 0X)

Test Water	Mean Time in Test[1] Water (Seconds)	Std. Dev.	Mean Percent of Time in Test Water	Std. Dev.
Brown Trout				
0.0X	601	132	50	11
0.1X	545	95	45	8
0.5X	245*	34	20*	2.8
1.0X	161*	33	13*	2.8
2.0X	96*	45	8*	3.7
4.0X	209*	87	17*	7.3
10.0X	333*	182	28*	15
Rainbow Trout				
0.0X	625	117	52	9.8
0.1X	91*	42	7.6*	3.5
0.5X	23*	6.6	1.9*	0.55
1.0X	25*	11	2.1*	0.9
2.0X	20*	7.9	1.6*	0.66
4.0X	27*	11	2.2*	0.95
10.0X	14*	8.4	1.1*	0.7

Note: 1X metals concentrations represent ambient Clark Fork River conditions as described in the text.

1 Total time of each test = 1,200 seconds.
* Values are significantly lower than control value ($\alpha = 0.05$).

Source: Appendix D.

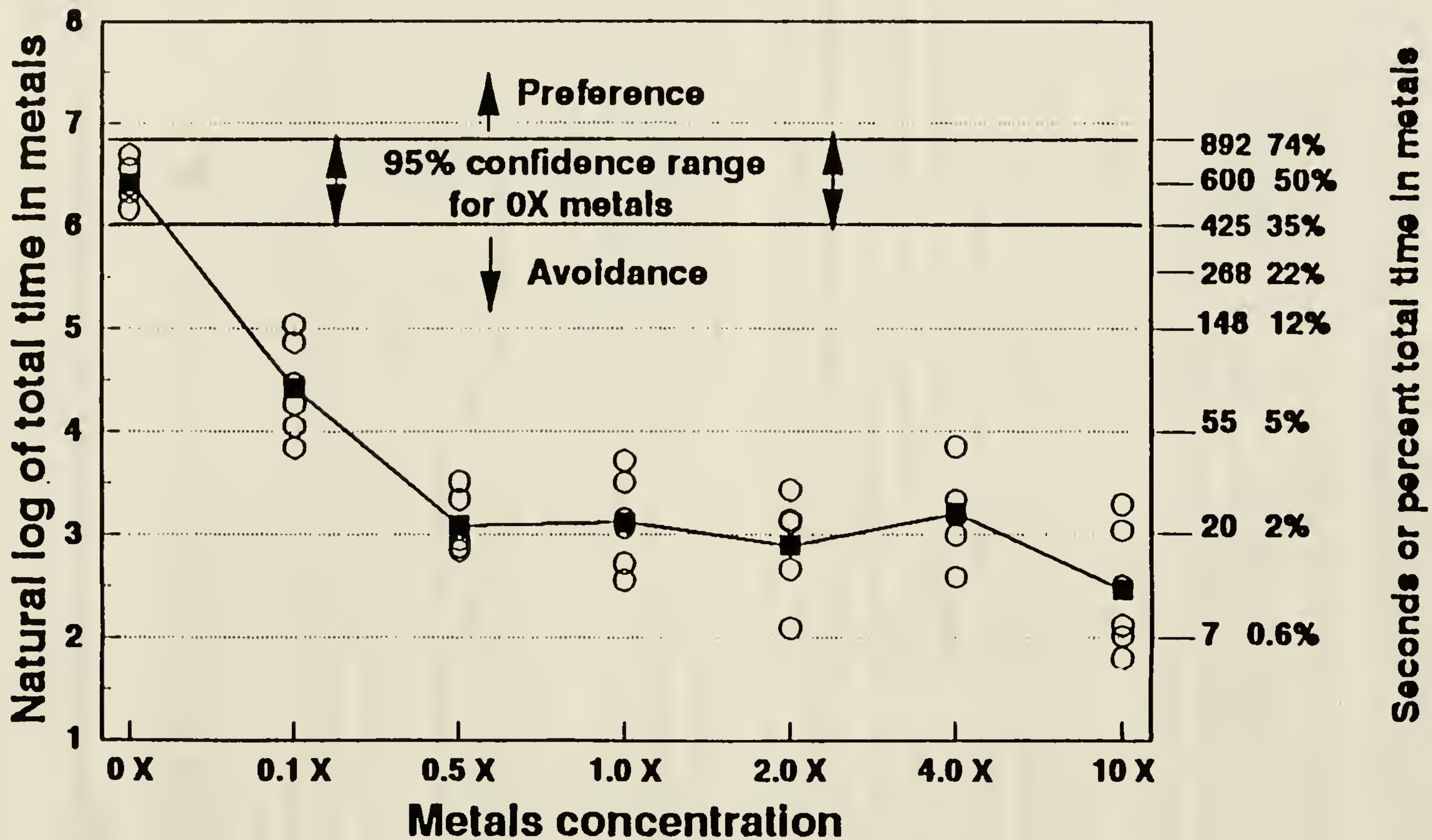

Figure 6-11. Avoidance Response of Brown Trout to Metals in Water. "1X" Concentration = 1.1 ppb Cd, 12 ppb Cu, 3.2 ppb Pb, 50 ppb Zn. Source: Appendix D.

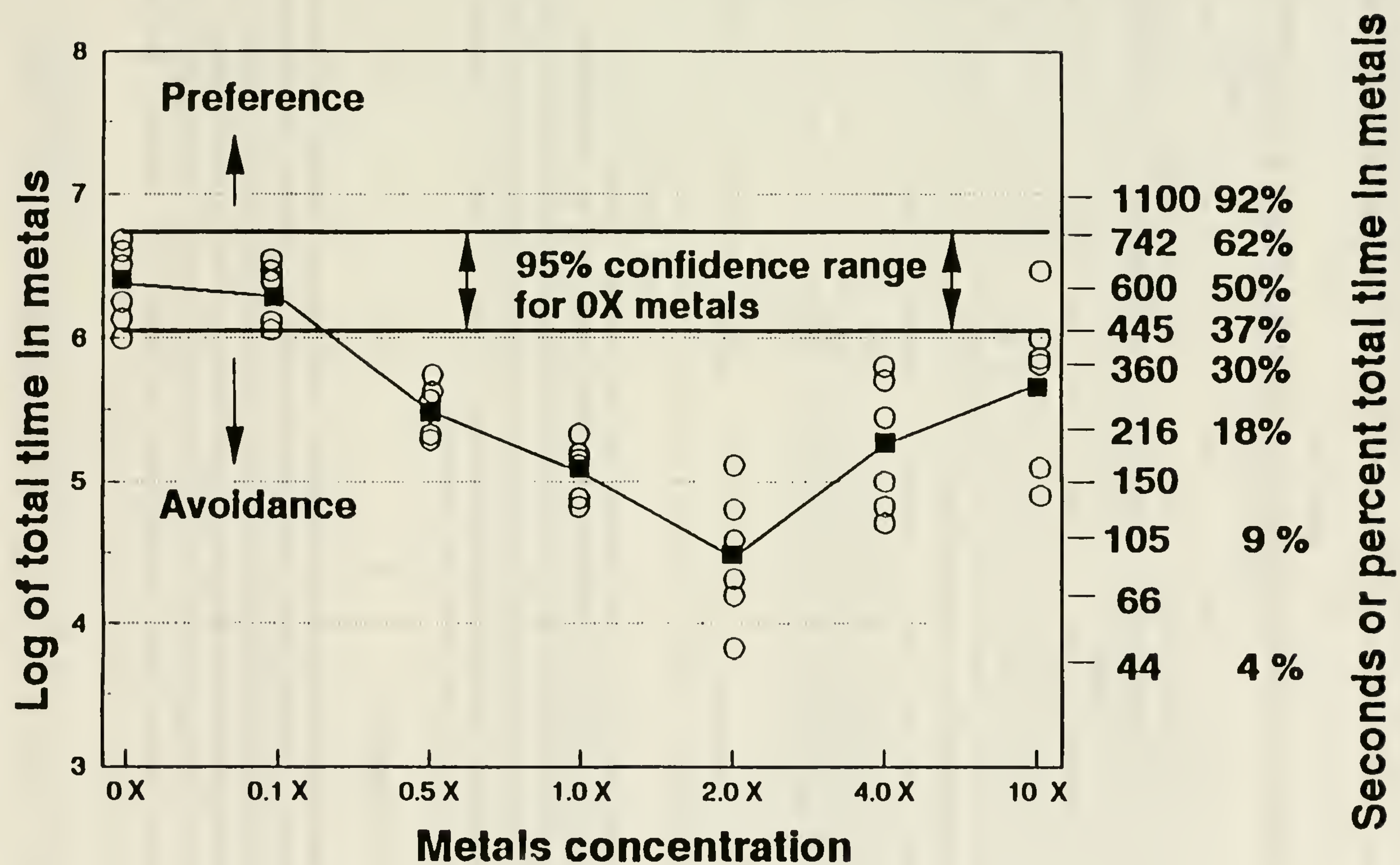

Figure 6-12. Avoidance Response of Rainbow Trout to Metals in Water. Source: Appendix D.

Table 6-11
Acclimated Rainbow Trout Avoidance Responses to Hazardous Substances in Surface Water (reference water = 1X)

Test Water	Mean Time in Test[1] Water (seconds)	Std. Dev.	Mean Percent of Time in Test Water	Std. Dev.
0.0X	1010**	84	84**	7
1.0X	598	72	50	6
4.0X	358*	96	30*	8

Note: 1X metals concentrations represent ambient Clark Fork River conditions as described in the text.

1 Total time of each test = 1,200 seconds.
* Values are significantly lower than control value (α = 0.05).
** Values are significantly higher than control value (α = 0.05).

Source: Appendix D.

To evaluate the reproducibility of the laboratory avoidance testing, a similar series of avoidance tests was performed at the National Fisheries Contamination Research Center (NFCRC) laboratory in Columbia, MO. Extremely close agreement was observed in the results of the independent tests performed at the two laboratories (see Delonay et al., 1995). This interlaboratory validation underlines the reproducibility of the avoidance testing and provides additional confirmation of the study findings.

Summary and Conclusions

Based on the demonstration of behavioral avoidance, both brown and rainbow trout have been injured in Silver Bow Creek and the Clark Fork River by exposure to hazardous substances. The results of these studies indicate that recruitment of trout from unimpacted tributaries (e.g., Rock Creek, Gold Creek, Warm Springs Creek) into the Clark Fork River is limited by behavioral avoidance of hazardous substances in the Clark Fork River. Further, the relatively greater sensitivity of rainbow trout is consistent with the absence of this species in the Clark Fork River upstream of its confluence with Rock Creek.

Finally, it should be noted that habitat generally limits the size of trout populations in unpolluted streams (Larkin, 1956; Chapman, 1966). Therefore, avoidance of Clark Fork

River water and reductions of trout populations in the Clark Fork River should not be offset by increases in tributary populations. Rather, overall populations will decrease.

6.4.7 Category of Injury: Death and Reduced Growth from Food Chain Exposure Pathway

As described in Chapter 5.0, benthic macroinvertebrates of the upper Clark Fork River Basin have accumulated elevated concentrations of hazardous substances as a result of exposure to hazardous substances in bed sediments and periphyton. Previous studies have shown that dietary uptake of cadmium, copper, lead, and zinc is a predominant pathway of metals accumulation in fish (Crespo et al., 1986; Wekell et al., 1986; Dallinger et al., 1987; Pratap et al., 1989). At sublethal dietary levels, cadmium interferes with calcium and magnesium uptake (Pratap et al., 1989) and copper has been shown to reduce growth in rainbow trout (Lanno et al., 1985; Julshamn et al., 1988). Dietary copper and lead also induced morphological and functional alteration of rainbow trout intestine as well (Crespo et al., 1986). A series of studies was conducted to assess the potential effects of this pathway (U.S. FWS and University of Wyoming, 1992; and Appendix E[13]). These studies, described in the following subsections, demonstrate that trout are injured, as manifested by increased mortality and reduced growth, from exposure to hazardous substances in their diets.

6.4.7.1 Milltown Endangerment Assessment (U.S. FWS and University of Wyoming, 1992)

As part of the Milltown Endangerment Assessment Project (U.S. FWS and University of Wyoming, 1992), rainbow trout were experimentally fed, in controlled laboratory experiments, forage fish and invertebrates collected from the Clark Fork River and the Snake River, WY (the control site). Growth, mortality, and bioaccumulation of hazardous substances in tissues were measured.

Initial Tests

Rainbow trout fry were exposed to combinations of hazardous substances in both their diet and in the water. The water exposures were based on the "1X" metals concentration representative of Clark Fork River conditions described in Section 6.4.5 (1.1 ppb Cd, 12 ppb Cu, 3.2 ppb Pb, and 50 ppb Zn). Trout were exposed to one of three water compositions (0X, 1X, 2X) and fed one of four test diets (Clark Fork River/Control invertebrates, Clark

[13] "Jackson Protocol P92-40050-10-02: Food Chain," by D.F. Woodward, H.L. Bergman, and C.E. Smith.

Fork River/Control forage fish[14]) for 91 days or until 80% mortality had occurred, whichever was first. To represent ambient conditions in the field, the diets were neither vitamin fortified nor pasteurized. In another series of studies, vitamin fortification/pasteurization was performed (see Section 6.4.7.2).

The concentrations (dry weight) of hazardous substances in each of the diets are shown in Table 6-12. The Clark Fork forage fish contained much higher levels of hazardous substances (As, Cd, Cu, Pb, Zn) than did the control fish. Arsenic, cadmium, and lead were below detection limits in the control fish; levels of the hazardous substances in the Clark Fork River forage fish ranged from 90% greater to over 3,000% greater than the hatchery fish. The Clark Fork River invertebrates had markedly higher levels of the hazardous substances than did the control invertebrates and both of the fish diets. Compared to the control invertebrates, the Clark Fork River invertebrates contained substantially greater concentrations of hazardous substance levels.

Table 6-12
Hazardous Substances in Fish and Invertebrates
(concentration in ppm, dry weight)

Diet	Arsenic	Cadmium	Copper	Lead	Zinc
Jackson (WY) hatchery fish (control)	< 2.1	< 0.082	4.6	< 1.7	109
Clark Fork River forage fish	6.9	0.45	39.1	3.27	218
Snake river (control) invertebrates	4.0	0.4	16.4	< 1.7	140
Clark Fork River invertebrates	53	3.9	460	40	640

Source: U.S. FWS and University of Wyoming, 1992.

Rainbow trout fed the Clark Fork River macroinvertebrate diet showed significantly greater mortality after 42 and 91 days than trout fed the control (Snake River) invertebrate diet (Figure 6-13). After 91 days, mortality was greater than 50% for all rainbow trout fed the Clark Fork River invertebrate diet, whereas mortality was less than 20% for the fish fed control (Snake River) invertebrate diets. These results indicate that the hazardous substances in the diet were the cause of the mortality, regardless of the water exposure.

[14] The Clark Fork forage fish (white suckers, red-side shiners, and slimy sculpins) and invertebrates (mostly *Hydropsyche* and *Tipula*) were collected near the Warm Springs Ponds; control invertebrates (mostly *Pteronarcys*, *Pteroarcella*, and *Arctopsyche*) were collected from the Snake River near Wilson, WY; control fish were obtained from the Jackson, WY fish hatchery.

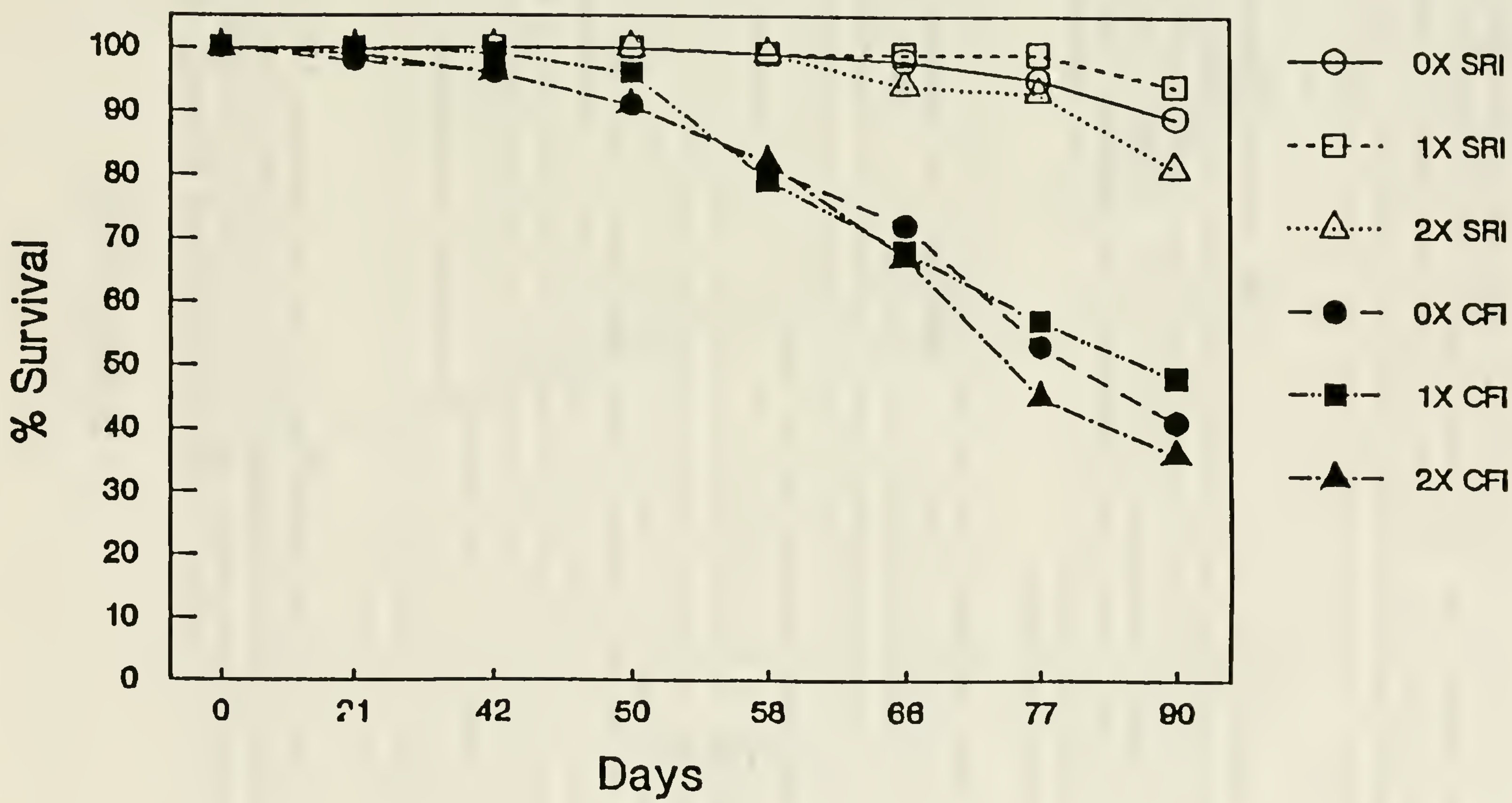

Figure 6-13. Survival of Rainbow Trout Exposed to Metals in Water (0X, 1X, 2X) and Food [Clark Fork River Invertebrates (CFI) and Snake River (Control) Invertebrates (SRI)]. Source: U.S. FWS and University of Wyoming, 1992.

In addition, growth in all fish fed the Clark Fork River invertebrate diet was significantly reduced compared to growth in fish fed the control (Snake River) invertebrate diet regardless of the water exposure (Figure 6-14). Test trout in the 0X water weighed 15% less than control trout in the 0X water after 42 days of exposure, and 39% less after 91 days. Lengths of test trout in all water treatments were significantly lower than in the respective control trout as well.

The presence of hazardous substances in the water made little difference to the mortality or growth of test trout on the Clark Fork River diet and control trout on the Snake River diet. For both control and test trout, mortality was only slightly higher after 91 days in the presence of the 2X metals concentrations than in the 0X or 1X. However, in both cases mortality was lower in the 1X than in the 0X treatments. Thus, hazardous substances in the food appeared to be primarily responsible for the increased mortality and decreased growth in rainbow trout observed in this study.

After 91 days of testing, histopathological examinations were performed on surviving fish. These examinations revealed healthy livers in trout on the Snake River invertebrate diet, whereas livers of trout on the Clark Fork River invertebrate diet showed signs of degeneration (see Section 6.4.8). Tissue concentrations of hazardous substances were also significantly higher in test trout on the Clark Fork River invertebrate diet than in control trout on the Snake River invertebrate diet, indicating that hazardous substances in the diets are biologically "available" and are accumulated by fish. After 91 days of exposure, copper in whole body tissue was over ten times higher in test fish than in control fish, and arsenic ranged from six to ten times higher. The water treatments in which fish were held did not make a significant difference in the bioaccumulation of copper or arsenic. Cadmium concentrations in test fish were significantly higher than in control fish in both diet-only and water-only exposures. When exposed to both contaminated water and contaminated diet, the resulting cadmium residue in whole body tissue was significantly greater than in either water or dietary exposure alone, and was much greater than in fish with no exposure at all. Lead residues were also affected by the water treatment. Whole body lead concentrations were not significantly different in test trout exposed to contaminated diet or contaminated water alone; however, trout exposed to both contaminated diet and water had significantly higher lead residues than did unexposed control fish.

The results of the tests using contaminated forage fish was less conclusive than with the invertebrates. Although mortality rates exceeding 80% were observed in all three of the test waters, it was postulated that the mortality may have been caused by malnutrition rather than by exposure to hazardous substances (U.S. FWS and University of Wyoming, 1992).

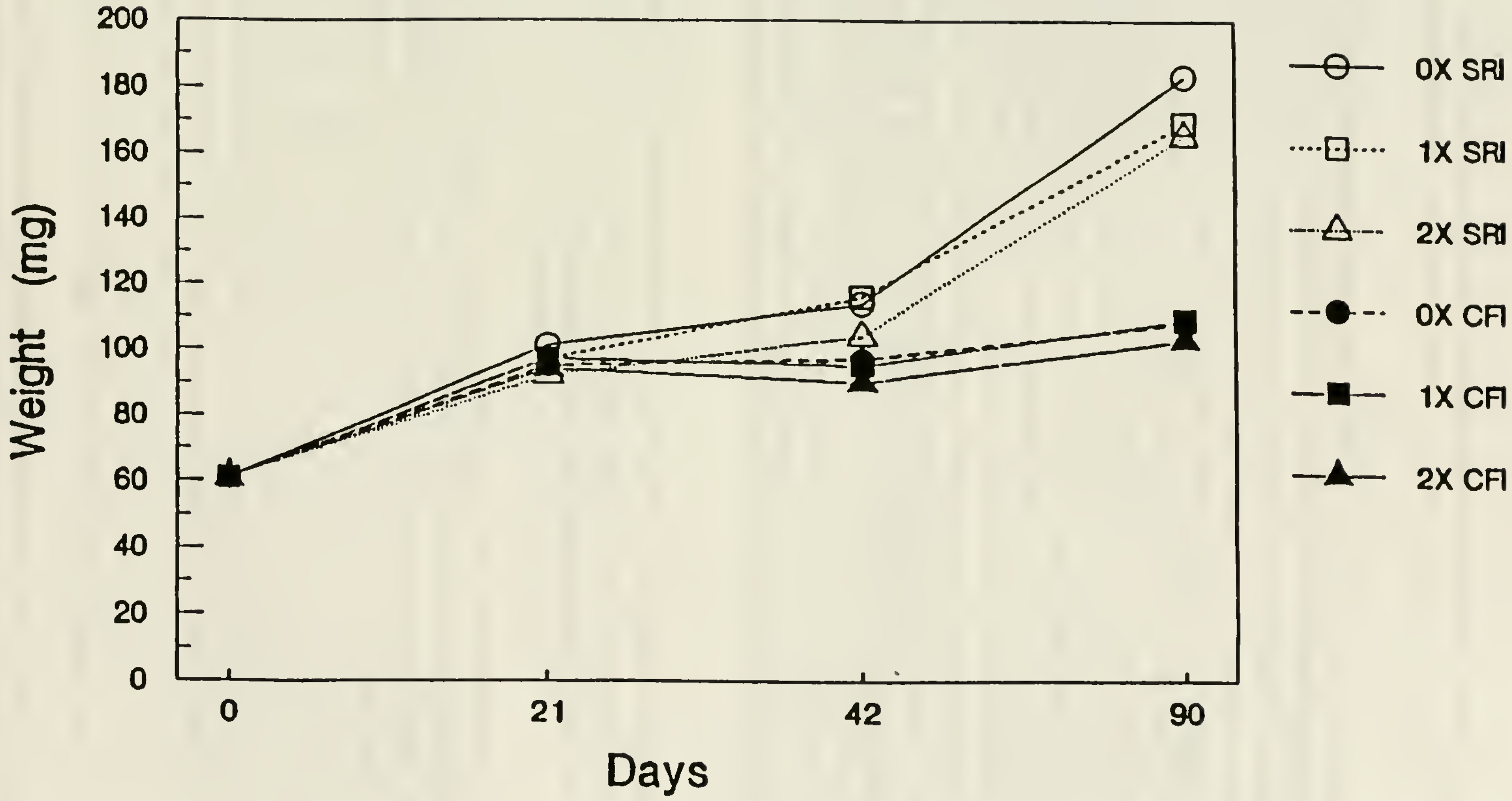

Figure 6-14. Growth of Rainbow Trout Exposed to Metals in Water (0X, 1X, 2X) and Food [Clark Fork River Invertebrates (CFI) and Snake River (Control) Invertebrates (SRI)]. Source: U.S. FWS and University of Wyoming, 1992.

Fortified Diets

A separate set of tests were conducted using nutrient-fortified and pasteurized Clark Fork forage fish and invertebrates collected from both the Warm Springs area and the Turah Bridge area to ensure that dietary effects were not caused by undernourishment. The fortified diets were dried and pelletized, reducing the percent moisture from near 90% to between 5% and 8%. The nutrient-fortified diets showed a similar pattern of elevated hazardous substance concentrations in Clark Fork River (Warm Springs) diets as did the unfortified diets. The nutrient-fortified Clark Fork River — Turah Bridge (control) invertebrates had far lower concentrations of hazardous substances in tissues than the Clark Fork River (Warm Springs) invertebrates (Table 6-13); therefore, these invertebrates were considered to be a "control" diet group. However, as shown in Chapter 5.0, and when compared to the Snake River controls, Turah Bridge invertebrates represent an extremely conservative control group, because the hazardous substance levels in their tissues are well above baseline levels. Rainbow trout in three different water exposures were fed one of four diets (Clark Fork River forage fish, Clark Fork River invertebrates, control invertebrates, and Biodiet, a stock hatchery trout food used as a control). The resulting *growth reductions* were similar to, although somewhat less than, the tests without the fortification (Table 6-14). Also, significant growth reductions were observed in the Clark Fork River (Turah Bridge) conservative control diet relative to either the biodiet or forage fish diet. However, in the fortified diet tests no significant mortality was observed.

Table 6-13
Hazardous Substances in Fish and Invertebrates
(concentration in ppm, dry weight)

Diet	Arsenic	Cadmium	Copper	Lead	Zinc
Biodiet hatchery food (control)	2.06	0.37	9.0	0.27	138
Fortified Clark Fork River forage fish	4.0	0.35	65	5.3	442
Fortified Turah Bridge invertebrates (control)	5.0	1.2	110	9.7	659
Fortified Clark Fork River invertebrates	43	2.4	417	29	1,076

Source: U.S. FWS and University of Wyoming, 1992.

6.4.7.2 Food Chain Study for Clark Fork River NRDA

A series of food-chain exposure tests similar to those described in Section 6.4.7.1 was performed as part of the Clark Fork River NRDA. The differences between the previous Milltown Endangerment work and the NRDA food chain studies are (1) the NRDA work

Table 6-14
Mean Lengths (mm) and Weights (g) of Rainbow Trout on Nutrient-Enhanced and Pasteurized Diets from the Clark Fork River, with Stock Hatchery Food as a Control

Diet	Day 43		Day 80	
	Weight	Length	Weight	Length
Biodiet fish food (control)	217	30	854	45
Clark Fork River forage fish	228	30	806	44
Clark Fork River Control (Turah Bridge) invertebrates	216	30	730**	43**
Clark Fork River (Warm Springs) invertebrates	152*	27*	410*	37*

* Significantly smaller ($\alpha = 0.05$) than any of the other three diets.
** Significantly smaller ($\alpha = 0.05$) than the Biodiet and forage fish; significantly larger than the Warm Springs invertebrate diet.

Source: U.S. FWS and University of Wyoming, 1992.

included brown trout as well as rainbow trout, (2) diets consisted only of nutrient-enhanced and pasteurized Clark Fork River invertebrates, and (3) water treatments consisted only of the 0X and 1X metals concentrations. Appendix E details the methods and results of these tests. A summary of these tests follows.

Macroinvertebrates were collected at three locations in the Clark Fork River: 2 km below Warm Springs Creek, 5 km below Gold Creek, and 2 km above Turah Bridge (Figure 6-15). These invertebrates, processed and pelletized with nutritional supplements, were fed to both brown and rainbow trout for 88 days. Trout were held in water that simulated ambient Clark Fork conditions (1X) (X = 1.1 ppb Cd, 12 ppb Cu, 3.2 ppb Pb, and 50 ppb Zn), while others were held in water without the metals (0X). The Clark Fork River/Turah Bridge diet again was used as a conservative control diet. As mentioned earlier, this control is conservative because bed sediments near Turah Bridge are contaminated with hazardous substances, and macroinvertebrates from Turah Bridge contain substantially higher hazardous substance concentrations than baseline concentrations in Snake River (WY) or Rock Creek (MT) invertebrates (see Chapter 5.0). Moreover, this diet was observed to cause significant growth reductions relative to biodiet or forage fish in the preceding study.

The three invertebrate diets had similar nutritional composition because of the nutrient fortification. However, the amount of accumulated metals in the invertebrates was much higher in the Warm Springs and Gold Creek invertebrates than in those from Turah Bridge.

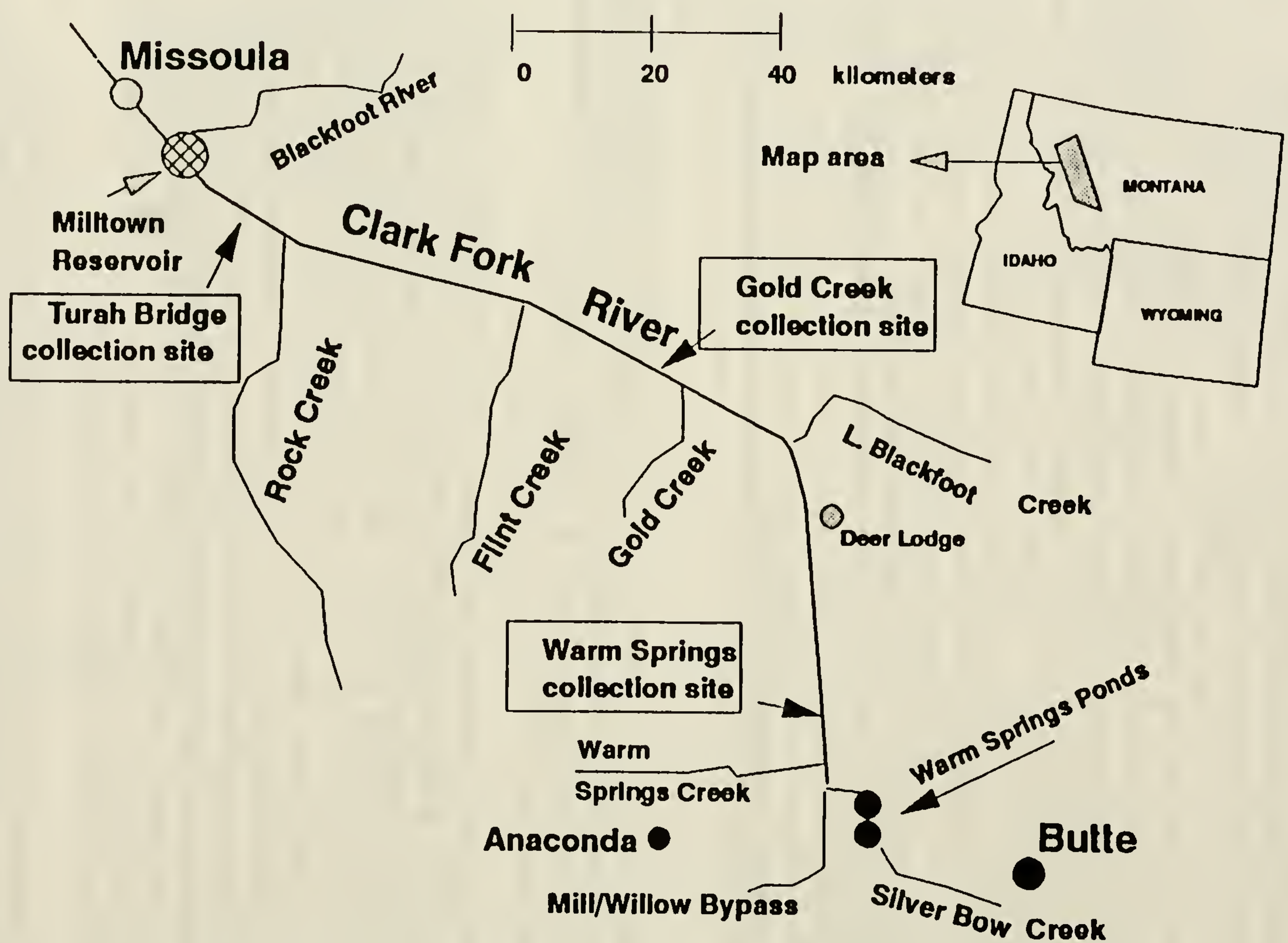

Figure 6-15. Location of Macroinvertebrate Sampling Sites in the Clark Fork River for Food-Chain Studies. Source: Appendix E.

Arsenic, copper, and lead levels in the upstream organisms (Warm Springs and Gold Creek) were more than twice the levels in the Turah Bridge organisms (Table 6-15). Cadmium was detected in Warm Springs organisms only. Although the Warm Springs invertebrates used in the Milltown Endangerment Assessment contained greater levels of hazardous substances than those in this study, high variability in metals concentrations in invertebrates has been documented in other studies and should not be considered anomalous (see Chapter 5.0). Despite the lower levels of hazardous substances in these Warm Springs invertebrates, the levels were still much higher than in the Turah Bridge invertebrates.

Table 6-15
Hazardous Substances (ppm) in Clark Fork River Invertebrate Diets

Location	Arsenic	Cadmium	Copper	Lead	Zinc
Turah Bridge	6.5 (6.9)	< 0.009 (< 0.010)	87 (92)	6.9 (7.3)	616 (655)
Gold Creek	10 (11)	< 0.009 (< 0.010)	178 (190)	15 (16)	650 (694)
Warm Springs	19 (21)	0.3 (0.3)	174 (190)	15 (16)	648 (707)

Note: Mean levels of hazardous substances in nutrient-fortified and pelletized Clark Fork River invertebrates collected from three different locations. The top number is the mean concentration in ppm wet weight. The number in parenthesis is the dry weight equivalent (ppm), based on the percentage of moisture in sample.

Source: Appendix E.

Lengths and weights of brown trout were recorded after 26 days, 52 days, and 88 days posthatch, while lengths and weights of rainbow trout were recorded at 18 days, 53 days, and 88 days posthatch. Comparisons were made between the growth of fish fed the three different diets in both contaminated (1X) and uncontaminated (0X) water.

As described in Appendix E, both lengths and weights of brown trout were found to be significantly reduced ($\alpha = 0.05$) in the two upstream diets compared to the Turah Bridge (control) diet (Table 6-16). Weights were significantly lower in all brown trout fed the Gold Creek and Warm Springs diet at days 26, 52, and 88 in both contaminated and uncontaminated water (0X). After 88 days, brown trout fed the Warm Springs diet weighed 39% less than those fed the Turah Bridge control diet in 0X water and 32% less than those fed the Turah Bridge control diet in 1X water. Moreover, exposure to both the contaminated diets and the contaminated (1X) water had a greater effect on growth than exposure to the

Table 6-16
Trout Growth Following Exposure to Metals-Contaminated Invertebrate Diet and Water

Test Diet/Water	Weight (mg) Day 26	Weight (mg) Day 52	Weight (mg) Day 88	Length (mm) Day 26	Length (mm) Day 52	Length (mm) Day 88
Brown Trout, 0X Water						
Turah Bridge (control)	74 (3.3)	175[a,*] (12)	568[a] (22)	23 (0.28)	28[a] (0.62)	40[a] (0.75)
Gold Creek	70 (2.5)	107[b] (5.8)	347[b] (9.7)	22 (0.35)	25[b] (0.47)	34[b] (0.29)
Warm Springs	68 (1.5)	112[b] (3.2)	344[b] (25)	22 (0.25)	25[b] (0.28)	33[b] (0.72)
Brown Trout, 1X Water						
Turah Bridge (control)	68 (1.9)	130[c] (10)	421[c] (59)	22 (0.2)	26[c] (0.4)	36[c] (1.6)
Gold Creek	67 (1.9)	94[d] (3.8)	267[d] (27)	22 (0.3)	24[d] (0.2)	31[d] (0.9)
Warm Springs	66 (1.0)	87[d] (15)	285[d] (42)	22 (0.2)	24[d] (0.9)	31[d] (1.6)

Note: Values are means, with standard deviations in parentheses, n = 4.

* Weight/length values with same letter are not significantly different ($\alpha = 0.05$).

Source: Appendix E.

contaminated diet alone (0X water). As shown in Table 6-16, weights and lengths of the fish fed all three diets were significantly reduced after 52 and 88 days in the 1X water relative to the 0X exposure. Indeed, even the fish fed the control diet (Turah Bridge) demonstrated a 25% reduction in weight and a 10% reduction in length when exposed to the 1X water concentration relative to the 0X water concentration.

Rainbow trout followed the same trend as the brown trout. Rainbow trout fed Warm Springs and Gold Creek diets had significantly reduced growth relative to those fed the Turah Bridge control diet after 53 and 88 days (Table 6-17). Figure 6-16 shows the visible size reduction in rainbow trout fed the contaminated invertebrate diet. However, for rainbow trout, no growth reductions were observed at the 1X water exposure relative to the diet-only (0X water) exposure.

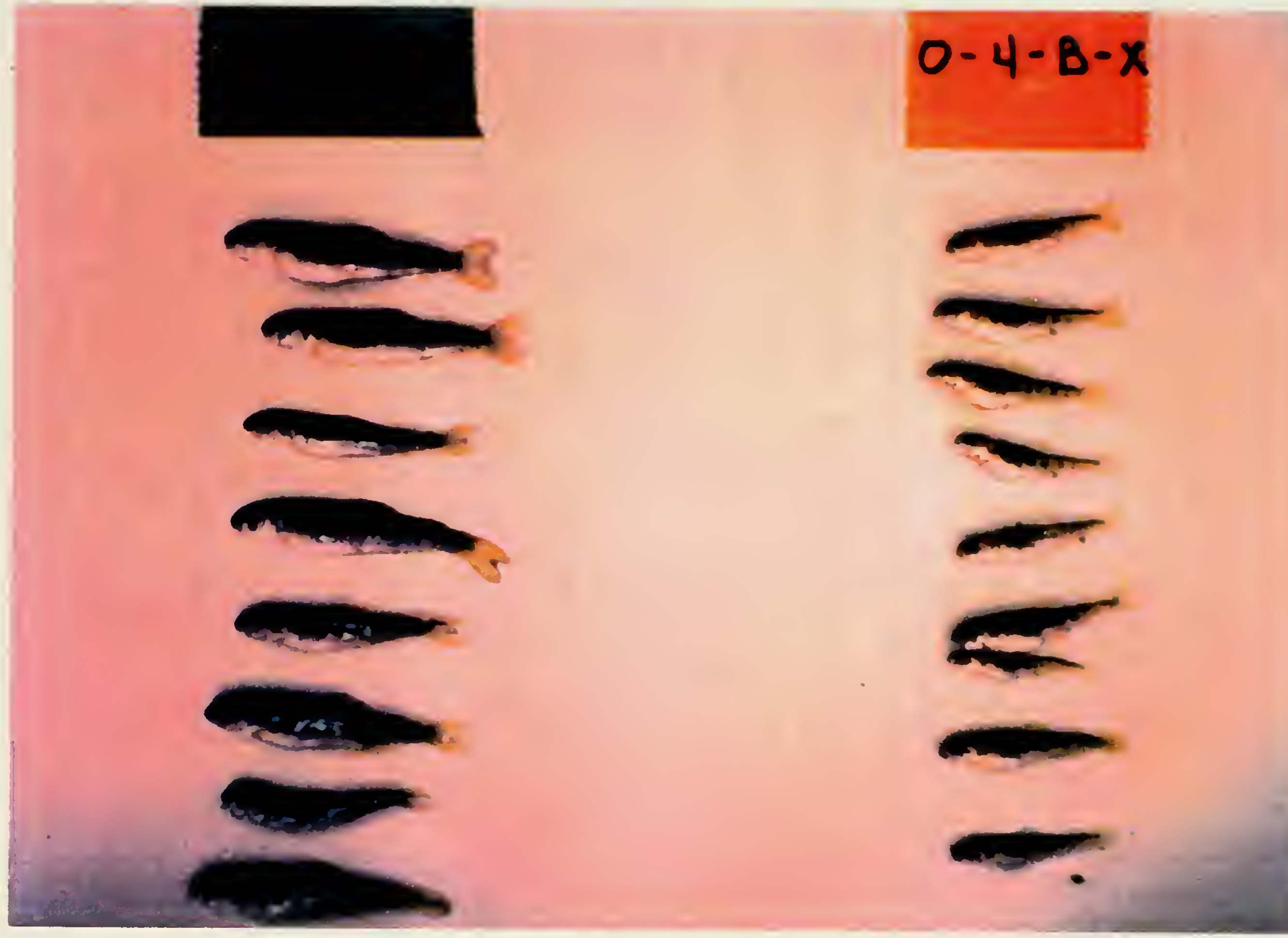

Figure 6-16. **Visible Differences in Rainbow Trout Growth after 88 d in 0X Test Water When Fed Warm Springs Invertebrates (Right Column) versus Turah Bridge (Control) Invertebrates (Left Column).** Source: Appendix E.

Table 6-17
Trout Growth Following Exposure to Metals-Contaminated Invertebrate Diet and Water

Test Diet/Water	Weight (mg) Day 18	Weight (mg) Day 53	Weight (mg) Day 88	Length (mm) Day 18	Length (mm) Day 53	Length (mm) Day 88
Rainbow Trout, 0X Water						
Turah Bridge (control)	94 (1.3)	455[a] (10)	1,408[a] (56)	-	38[a] (0.4)	53[a] (0.7)
Gold Creek	94 (3.2)	227[b] (14)	758[b] (41)	-	30[b] (0.5)	42[b] (0.8)
Warm Springs	92 (1.7)	224[b] (12)	789[b] (41)	-	30[b] (0.4)	42[b] (0.6)
Rainbow Trout, 1X Water						
Turah Bridge	92 (2.8)	435[a] (16)	1,374[a] (45)	-	37[a] (0.3)	52[a] (0.5)
Gold Creek	92 (1.8)	225[b] (3.8)	830[b] (9.1)	-	30[b] (0.1)	43[b] (0.1)
Warm Springs	92 (1.6)	233[b] (14)	801[b] (36)	-	30[b] (0.5)	42[b] (0.9)

Note: Values are means, with standard deviations in parentheses, n = 4. No length data were collected on Day 18.

* Values with same letter are not significantly different ($\alpha = 0.05$).

Source: Appendix E.

Length differences, although significant, were less pronounced than weight differences in both brown and rainbow trout, though after 53 and 88 days trout on upstream diets were shorter than those on the Turah Bridge diet (Tables 6-17 and 6-18).

Summary and Conclusions

These two sets of studies demonstrate that exposure to hazardous substances via food-chain pathways results in injuries to fish, including both mortality and reduced growth. In the first study (U.S. FWS and University of Wyoming, 1992), exposure to hazardous substances in invertebrates was found to cause both significant mortality and reduced growth. The second study (Appendix E) did not demonstrate significant mortality. However, this latter study was

Table 6-18
Summary of Mean Hazardous Substance Concentrations (ppm) in Clark Fork River (CFR) Invertebrates Used in Food-Chain Studies. Also shown is degree of injury response in brown trout.

	As	Cd	Cu	Pb	Zn	Significant Mortality?	Approximate Weight Percent Reduction after 88-91 Days
CFR - WSP[1]	53	3.9	460	40	640	Yes	80%
Fortified CFR - WSP[2]	43	24	417	29	1,076	No	44%
Fortified CFR - WSP[3]	19	0.3	174	15	648	No	39%
Fortified CFR - GC[4]	10	ND	178	15	650	No	39%

1 Clark Fork River - Warm Springs Ponds diet (U.S.FWS and University of Wyoming, 1992). See Section 6.4.7.1)
2 Fortified Clark Fork River - Warm Springs Ponds diet (U.S.FWS and University of Wyoming, 1992). See Section 6.4.7.1. Growth compared with Turah Bridge diet.
3 Fortified Clark Fork River - Warm Springs Ponds diet (Appendix E). See Section 6.4.7.2. Growth compared with Turah Bridge diet.
4 Fortified Clark Fork River - Gold Creek diet (Appendix E). See Section 6.4.7.2. Growth compared with Turah Bridge diet.

more conservative than the original study because (1) the concentrations of hazardous substances found in the field-collected invertebrates were somewhat lower, and (2) the invertebrates were fortified with vitamins and minerals and pasteurized. As stated in Appendix E:

> "...early life stage trout in the Clark Fork River must sustain themselves on an invertebrate food source that is neither pasteurized nor has vitamins or minerals added. In our attempt to control for causes of mortality other than metals, we probably improved the natural food source and hence reduced the severity of toxicological effects."

Table 6-18 summarizes the results of the food-chain studies (U.S. FWS and University of Wyoming, 1992; Appendix E). As shown in the table, concentrations of hazardous substances were highest in the first study, conducted with unfortified diets. Resulting injuries included both death and reduced growth. Subsequent studies performed using fortified diets demonstrated reduced growth only (no lethality). However, hazardous substance concentrations in these diets were lower and nutrient-enhancement was provided in the food.

Overall, therefore, the results of these studies demonstrated that consumption of metal contaminated invertebrates from the Clark River causes injuries (including lethality and reduced growth) to trout.

6.4.8 Category of Injury: Reduced Growth and Physiological Health Impairment

This section describes growth and health impairment injuries to trout as demonstrated in controlled laboratory studies and in free-ranging organisms collected from the Clark Fork River. These injuries included:

- Reduced growth
- Physiological health impairment
  - Degeneration of the digestive system, as evidenced by pancreatic and intestinal cell degeneration, swollen abdomens, and gut Impaction
  - Liver cell damage
  - Increased lipid peroxidation, an indicator of cell damage.

In addition to these measures of physical injury, tissue residues of hazardous substances are presented as indicators of exposure in laboratory and free-ranging organisms.

6.4.8.1 Reduced Growth Injuries: Laboratory Studies

Reduced growth has been documented during sublethal, chronic exposures resulting in acclimation to Zn and Cu mixtures (Finlayson and Verrue, 1980) and to Zn, Cu and Cd mixtures (Roch and McCarter, 1984; Roch and McCarter, 1986). In these studies, reduced growth was considered to be a sensitive measure of the deleterious effect of these metals mixtures. During sublethal exposures that resulted in acclimation to individual metals, reduced growth also has been documented for Zn (Hobson and Birge, 1989) and Cu (Dixon and Sprague, 1981; Collvin, 1984; Sprague, 1985). Reduced growth associated with chronic exposure to metals such as Zn, Cu, and Cd is considered to be the physiological cost of acclimation (Sprague, 1985; Hobson and Birge, 1989).

In conjunction with the acclimation studies described above and in Appendix C, physiological and growth impairment injuries were assessed in fish from the acclimation exposures. The sub-lethal effects of chronic exposure to metals were evaluated by determining metal-residue concentrations in the livers of fish, and by determining the weights of fish following exposure to the metals. In addition to growth and residue measurements, metallothinein was

measured.[15] Metallothionein (MT) is a metal-binding protein that is capable of binding and detoxifying metals. Laboratory experiments and field studies have confirmed that MT in fish is induced by exposure to metals such as cadmium, copper, and zinc (reviewed in Hogstrand and Haux, 1991).

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[15] This information is not described in Appendix C. Methods used for the referenced study are as follows: Randomly selected fish from the acclimation and control exposures were sacrificed on days 0, 10, and 20 into the acclimation and on day 14 following the de-acclimation for determination of metallothionein (MT) and tissue-metal residue concentrations. Fish were immediately pithed and the liver removed, rinsed in deionized water and blotted dry, placed in sealed cryostatic vials, frozen in liquid nitrogen and stored at -70 °C. At a later date, thawed livers were individually weighed and homogenized in 50 mM Tris-HCl (pH 8.0, 1 °C, at a minimum of 1:3 weight:volume ratio). Aliquots of 500 µL were taken from each homogenate, weighed, and acidified with 3 mL of 70% Instra-Analyzed HNO_3 for AAS analysis of Zn, Cu, Cd and Pb. The remainder of each homogenate was centrifuged at 8,800 rpm, 4 °C for 10 min. Two 500-µL aliquots were taken from each supernatant, frozen in liquid nitrogen and stored at -70 °C for subsequent MT analysis by a competitive double-antibody radioimmunoassay (RIA) for fish MT. The RIA was developed by Hogstrand and Haux (1990) and later modified for rainbow trout MT by Hogstrand et al. (1994). The MT assay used rabbit antiserum raised against MT for perch *(Perca fluviatilis)* as the first antibody, ^{125}I-labelled rainbow trout MT as a tracer, and goat anti-rabbit IgG as a second antibody. A 10,000xg supernatant prepared from livers of Cd-injected rainbow trout was used as the MT standard. The MT content of the standard was calibrated against a standard curve prepared from rainbow trout MT (Hogstrand et al., 1994). The working range of the RIA was 10 - 100 ng rainbow trout MT per assay tube, which corresponds to 0.6 - 6.0 µg/g liver wet weight. No purified brown trout MT was available so rainbow trout MT was also used as the standard for measurement of MT from brown trout. Since there may be structural dissimilarities in the antigenic determinants of MT from both species, the reported values of MT from brown trout in this study should be considered as relative.

Concentrations of Zn, Cu, Pb, and Cd in tissue were determined by AAS using a graphite furnace or flame (Perkin-Elmer model 2380 and model 372). Blank, spike, standard, and replicate analyses of the same samples used to evaluate quality control were used to verify instrument calibration and accuracy. Blanks always had metals concentrations below the detection limits of the instrument; method detection limits (in µg/L) were 4.9 Zn, 4.6 Cu, 1.7 Pb and 0.4 Cd. Spikes introduced at the beginning of sample preparation and spikes added to digestates showed an average recovery of > 90%; standards were generally within 10% of the theoretical values; and values for the second replicate analysis generally were within 10% of the first value. Analyses were rejected and samples rerun if values for standards were not within 20% of the theoretical values. ANOVA was used to evaluate differences in MT concentrations, metals concentrations, and weights among acclimated and control fish within each species. Because the main effects of time on MT and Cu concentrations were not significant for any species/stock, the data from the various sample periods during the acclimation to metals were pooled for comparisons among acclimation and control groups. Partial correlation analysis (Zar, 1984) was performed to identify, in the computed correlation matrix, which metal(s) accumulated (µg/g) in the liver had significant correlation with MT concentration. Finally, Pearson's product-moment correlation (Zar, 1984) was used to calculate correlation coefficients between the identified metal and MT concentrations.

Reduced Growth

The results of the growth evaluation demonstrated weight reduction in both the hatchery and Clark Fork brown trout exposed to low-levels of metals (Figures 6-17a and 6-17b).[16] The brown trout also demonstrated the greatest degree of acclimation to the metals (Section 6.4.5.2). In contrast, hatchery rainbow trout did not show reduced growth (Figure 6-17c), but were less able to acclimate to the metals and demonstrated more rapid mortality.

In the field assessment study of physiological impairment in resident brown trout from the upper Clark Fork River (see below), a reduction was found in the growth condition factor of fish collected from the Clark Fork River/Warm Springs relative to baseline, although this reduction was not statistically significant at the 5% level. Additionally, in a laboratory study conducted as part of the Milltown Endangerment Assessment (Section 6.4.7.1), growth of fish was reduced as a result of feeding fish the contaminated Clark Fork River invertebrate diet. Similarly, as described in Section 6.4.7.2 and in Appendix E, a feeding study conducted for the NRDA showed reduced trout growth when fish were fed contaminated invertebrates collected from the Clark Fork River. The observed growth reductions in each of these studies illustrates a consistent pattern of growth reduction injuries caused by exposure to hazardous substances.

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[16] Differences in weight between controls and metals-acclimated fish were evident in hatchery and Clark Fork brown trout, but not hatchery rainbow trout (Figure 6-17a-c). The effect of acclimation and time on weight was significant in hatchery brown trout (acclimation, $F_{1,174} = 42.51$, $p < 0.001$; time, $F_{2,174} = 27.24$, $p < 0.001$) and in Clark Fork brown trout (acclimation, $F_{1,118} = 22.45$, $p < 0.001$; time, $F_{1,118} = 36.33$, $p < 0.001$), but only the effect of time was significant in hatchery rainbow trout ($F_{2,173} = 36.40$, $p < 0.001$). The interaction effect was not significant for any species/stock. At each time interval throughout the acclimation and de-acclimation periods, pairwise comparisons revealed significant differences in weights between controls and acclimated or de-acclimated groups for hatchery brown trout (Figure 6-17a). Significant difference in weights between control and acclimated group was found at the five week interval for Clark Fork brown trout (Figure 6-17b). No significant differences in weight between controls and acclimated groups were found for hatchery rainbow trout (Figure 6-17c).

No differences in food consumption or feeding behavior were apparent between acclimated and control fish or between species/stock. Daily observations revealed that both acclimated and control fish of each species/stock consumed approximately 90-100% of their daily ration within an equivalent time period. Thus, food consumption or feeding behavior was not considered a potential variable in determining differences in growth among exposure groups or among species/stocks.

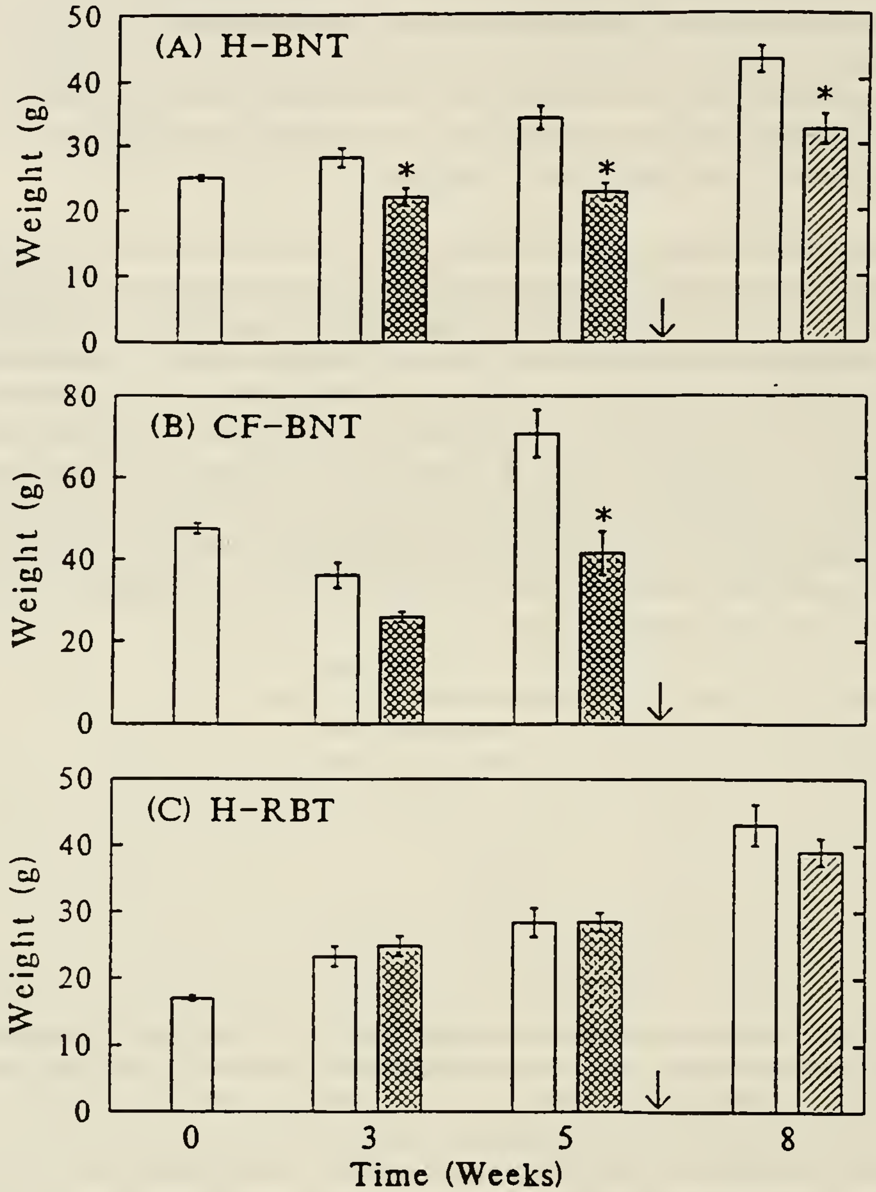

Figure 6-17. Mean (±1 SEM; n = 30) weight of (a) hatchery brown trout (H-BNT), (b) Clark Fork brown trout (CF-BNT), and (c) hatchery rainbow trout (H-RBT). Fish were exposed to either control water (represented as open bar), acclimation conditions (represented as cross-hatch bar; 0.2P concentrations), or de-acclimation conditions (represented as single hatch bar; 0.2P→C, initial de-acclimation time indicated by arrow). For each species/stock and time of acclimation, significant differences ($p < 0.05$) between mean values for control and acclimated or de-acclimated weights are indicated by asterisks.

Metallothionein and Metal Residues

In addition to demonstrated growth reductions, metallothionein concentrations were higher in metals-exposed hatchery brown and rainbow trout compared to the controls; this comparison was not significant for the Clark Fork brown trout at the 5% level, although metallothionein was greater in the acclimated Clark Fork fish relative to the pre-acclimated Clark Fork trout (Figure 6-18, panel I).[17] Table 6-19 shows copper residues measured during the acclimation study. Despite being held in laboratory control water for a month prior to testing, copper concentrations in Clark Fork brown trout were greater than in the hatchery brown or rainbow trout at the initiation of the study. Following the acclimation exposures (0.2P), copper residues increased in all three species/stocks; however, this increase was not significant for the Clark Fork fish.

Statistical analysis of the metallothionein and metal residue data demonstrated that MT was significantly correlated with copper residues for all species/stocks.[18] This indicates that exposure to the metals caused metal accumulation, metallothionein production, and reduced growth. This result is consistent with the scientific literature.

Overall, the results of these studies show that:

- Trout exposed to sub-lethal concentrations of hazardous substances similar to those measured in the Clark Fork River demonstrated significant growth reductions increased levels of metallothionein, and increased copper levels in tissues.

- Metallothionein concentrations were significantly correlated with copper residues. Metallothionein has been shown in the scientific literature to be associated with reduced growth.

- Brown trout were found to have a greater ability to acclimate to metals, greater increases in metallothionein, and greater growth reductions than rainbow trout.

[17] MT concentrations in liver were highest ($p < 0.05$) in fish exposed to metals compared to the control fish, for both hatchery brown and rainbow trout, but not in Clark Fork brown trout (Figure 6-18, panel I). Overall, however, the main effect of acclimation on MT concentration was significant for each of the three species/stock (hatchery brown trout, $F_{2,55} = 54.55$, $p < 0.001$; Clark Fork brown trout, $F_{2,46} = 7.16$, $p < 0.005$; hatchery rainbow trout, $F_{2,55} = 5.01$, $p < 0.05$). The interactions of acclimation and time were not significant, nor were the main effects of time for any species/stock.

[18] The matrix of partial correlation coefficients for MT and all metal-residue concentrations in the livers of each species/stock identified Cu as the only metal significantly ($T = 5.35$, $p < 0.001$) correlated with MT. The subsequent tests for correlation between Cu and MT showed significant ($p \leq 0.001$) positive associations for each species/stock, with each brown trout stock $R^2 \geq 0.60$ (Figure 6-18a and 6-18b, panel II) and hatchery rainbow trout $R^2 = 0.42$ (Figure 6-18c, panel II).

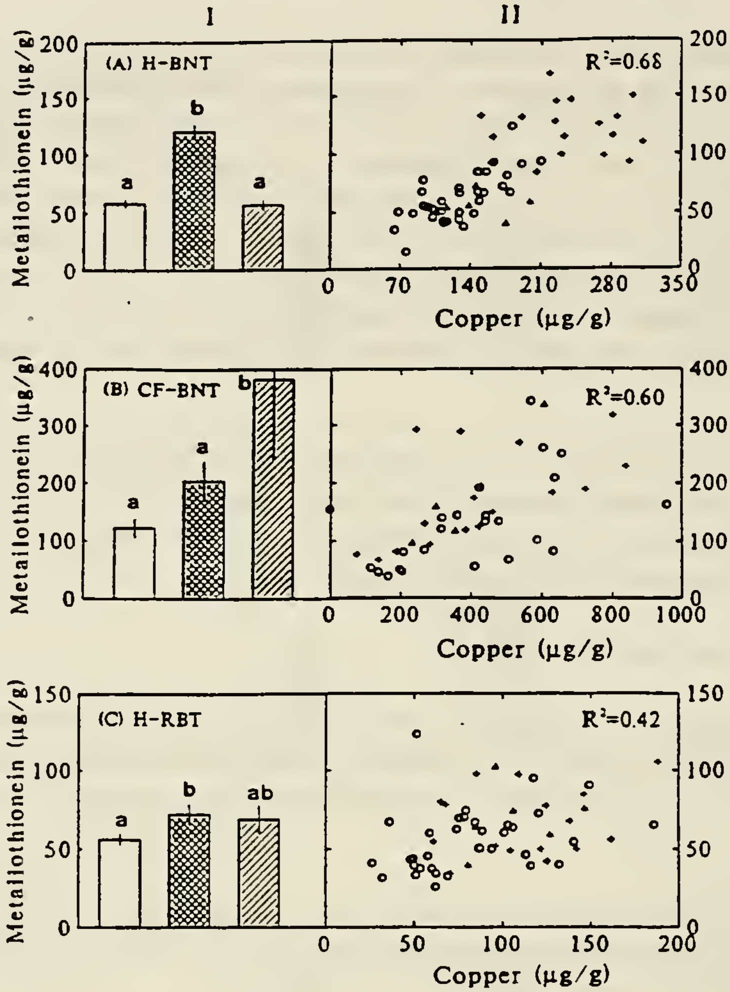

Figure 6-18. **Hepatic metallothionein and Cu concentrations (µg/g) in (a) hatchery brown trout, (b) Clark Fork brown trout, and (c) hatchery rainbow trout exposed to either control water (represented as open bar and "o" symbol), acclimation conditions (represented as cross-hatch bar and "+" symbol; 0.2P metals concentrations), or de-acclimation conditions (represented as single hatch bar and "▲" symbol; 0.2P→C).** For each species/stock, (left panel, I) mean values (+1 SEM) shown with the same letter superscript are not significantly different ($p < 0.05$). And for each species/stock, (right panel, II) copper and metallothionein were significantly correlated ($p \leq 0.001$, R^2 = correlation coefficient). The coordinates for two samples are not depicted in the plot (panel II) for the Clark Fork brown trout (B) de-acclimated fish because of the scales used; these two samples had Cu concentrations of 1,106.5 and 1,427.9 and respective metallothionein concentrations of 969.3 and 615.8.

Table 6-19
Mean Measured Copper Concentrations in Liver Tissue
(µg/g, wet weight, standard deviation in parenthesis) from Fish Exposed to Either Control Water, Acclimation Water, or De-Acclimation Water

Species/Stock	Exposure	Cu
Hatchery Brown	Control (n = 34) Acclimation (n = 18) De-acclimation (n = 6)	129.01 (36.75) 236.86 (50.33) 190.43 (90.80)
Clark Fork Brown	Control (n = 25) Acclimation (n = 18) De-acclimation (n = 6)	403.43 (217.71) 413.26 (221.47) 671.39 (489.24)
Hatchery Rainbow	Control (n = 34) Acclimation (n = 18) De-acclimation (n = 6)	82.88 (36.51) 120.28 (41.98) 106.89 (25.49)

Therefore, accumulation of hazardous substances in tissues and metallothionein production should be viewed both as indicators of exposure to hazardous substances, as well as indicators of growth reduction injuries. For example, in the field assessment study of physiological impairment in resident brown trout from the upper Clark Fork River (see below at Section 6.4.8.2), elevated MT was found in livers of fish from the Clark Fork River below Warm Springs relative to the Clark Fork/Turah Bridge and reference sites. This field study also demonstrated elevated concentrations of Cu (as well as As and Cd; Zn was not measured) in several tissues sampled, including liver. Residue concentrations of Cu in liver were comparable in the laboratory-exposed brown trout from the acclimation studies and in these field-collected brown trout. It is reasonable to conclude, based on the results of the laboratory study, that these wild-caught fish with elevated metals and metallothionein would also demonstrate growth reduction injuries.

6.4.8.2 Health Impairment Laboratory Studies

In conjunction with the food-chain studies described above, health impairment injuries were assessed in fish exposed to the contaminated invertebrate diets.[19] At the termination of the feeding studies, eight fish of each species were selected for the following measurements:

[19] A description of these studies is presented in Appendix F, "Research Report on Injury Determination, Fishery Protocol #2," by H.L. Bergman.

- Tissue concentrations of hazardous substances
- Histopathological examination
- Lipid peroxidation
- Autopsy assessment.

Tissue metals concentrations were measured to assess exposure of fish at the tissue level and as a potential indicator of growth reduction injuries. *Histopathological examination* was performed to assess the health of gill, liver, kidney, gastrointestinal tract, and pancreatic tissues. *Lipid peroxidation* was measured because it is an indicator of cell damage. *Autopsy assessment* was performed to evaluate any abnormalities associated with length, weight, eyes, gills, head, fins, spleen, kidney, liver, and bile. The methods used for the above techniques are described in Appendix F.

Tissue Concentrations of Hazardous Substances

Brown trout fed the contaminated Gold Creek and Warm Springs invertebrate diets accumulated significantly higher concentrations of both copper and lead than those fed the control (Turah Bridge) diet at both the 0X and 1X water exposure (Table 6-20 and Figure 6-19). Similarly, both brown and rainbow trout fed the Gold Creek and Warm Springs diets accumulated significantly higher concentrations of arsenic than those fed the control diets at both the 0X and 1X water exposure. Brown and rainbow trout both accumulated significantly greater concentrations of cadmium from the contaminated diets relative to the control diets. However, for brown trout, this accumulation was only significant at the most upstream site (Warm Springs diet) at the 0X water concentration; for rainbow trout, accumulation was only significant at the 1X water concentration.

Histopathological Assessment

As described in Appendices E and F, brown trout fed the contaminated diets demonstrated physiological abnormalities. These included reduced amounts of zymogen — precursors of digestive enzymes commonly found in pancreatic cells — in brown trout fed the contaminated Clark Fork River invertebrates (Warm Springs diet). In addition, degeneration of pancreatic cells was observed in fish fed the Clark Fork River invertebrates (Warm Springs diet). These effects were not observed in rainbow trout. However, rainbow trout demonstrated greatly reduced feeding activity when fed the two upstream Clark Fork River contaminated diets (Warm Springs, Gold Creek) (Appendix E). Thus, poor feeding may explain the absence of effects in rainbow trout (Appendix E).

Lipid Peroxidation

As described in Appendix F, brown trout fed the Clark Fork River/Warm Springs invertebrate diet were found to have greater lipid peroxidation than those fed invertebrates from the downstream sites (Gold Creek and the control, Turah Bridge). Fish fed invertebrates from the

Table 6-20
Whole Body Tissue Concentrations (ppm, wet weight)

Diet	Water	Arsenic	Cadmium	Copper	Lead
Brown Trout					
Turah Bridge (control)	0X	0.19	0.04	2.44	0.19
Gold Creek	0X	0.66[a]	0.05	5.26[a]	0.48[a]
Warm Springs	0X	0.74[a]	0.09[a]	6.80[a]	0.85[a]
Turah Bridge (control)	1X	0.18	0.09[a]	3.53	0.52[a]
Gold Creek	1X	0.71[a,b]	0.13[a,b]	6.88[a,b]	0.88[a,b]
Warm Springs	1X	0.79[a,b]	0.15[a,b]	8.23[a,b]	0.78[a,b]
Rainbow Trout					
Turah Bridge (control)	0X	0.28	0.05	3.08	0.23
Gold Creek	0X	0.58[a]	0.04	3.19	0.19
Warm Springs	0X	0.72[a]	0.04	4.27	0.25
Turah Bridge (control)	1X	0.22	0.14[a]	2.89	0.39
Gold Creek	1X	0.58[a,b]	0.10[a]	3.38	0.21
Warm Springs	1X	0.63[a,b]	0.16[a]	4.01	0.46

[a] = Significantly greater than control/0X water ($\alpha = 0.05$).
[b] = Significantly greater than control/1X water ($\alpha = 0.05$).

Source Appendix F.

Gold Creek location were found to have greater lipid peroxidation than those fed invertebrates from the Turah Bridge control site (Table 6-21). There was no increased lipid peroxidation in rainbow trout. Again, poor feeding may explain the absence of effects in rainbow trout.

Autopsy Assessment

As described in Appendix E, the most apparent physical deformations observed in the autopsy assessment was the appearance of swollen abdomens and gut impaction in brown trout (Figure 6-20). Brown trout fed the contaminated Warm Springs invertebrate demonstrated 4% and 9% occurrence of gut impaction in the 0X and 1X water exposures, respectively. Brown trout fed the contaminated Gold Creek diets demonstrated a 3% occurrence of gut impaction. The condition was not observed in either the Gold Creek/1X water exposure or in any controls (Turah Bridge diets). The condition was not observed in any rainbow trout.

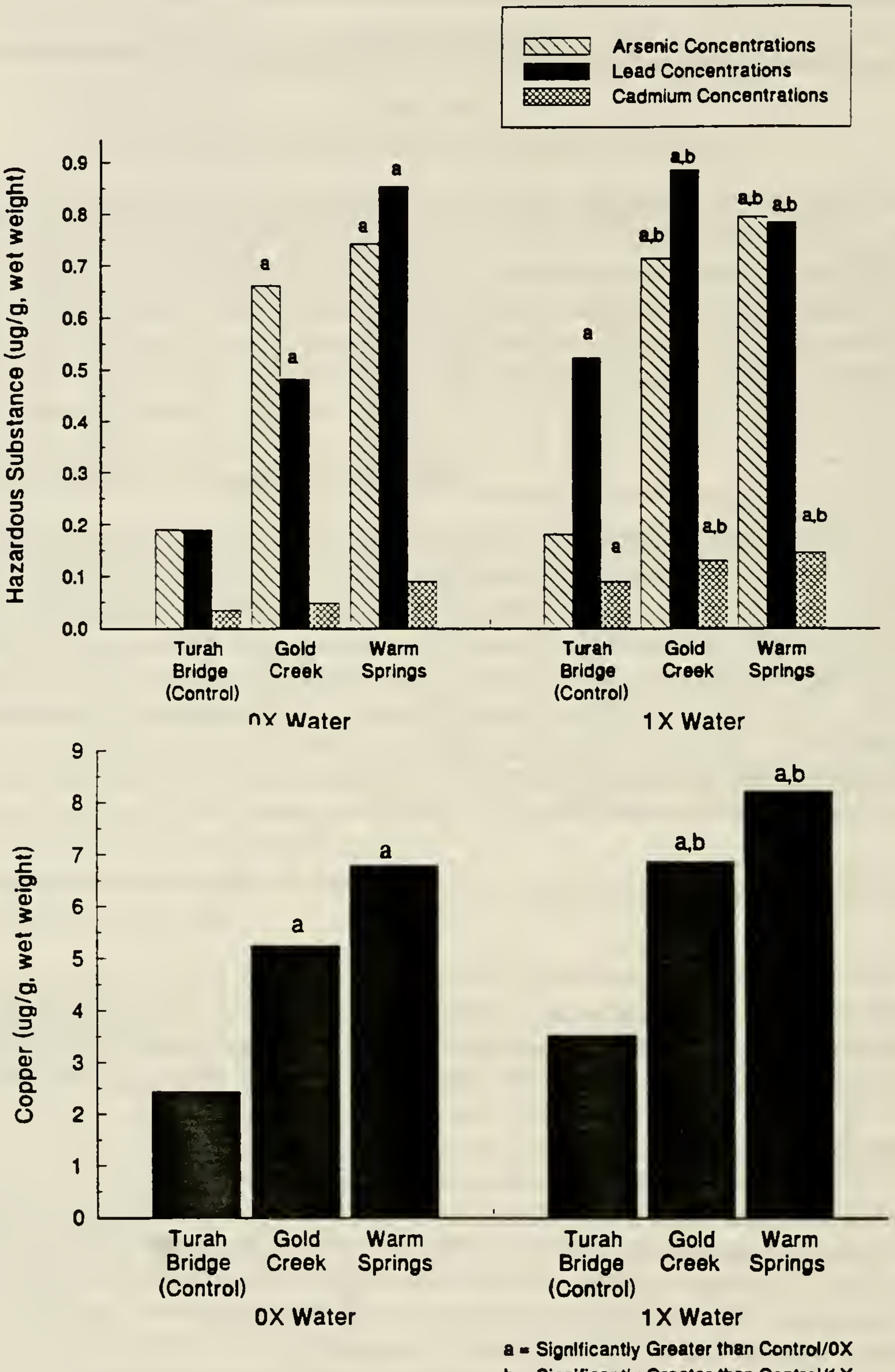

Figure 6-19. **Whole Body Concentrations of Hazardous Substances in Brown Trout Fed Contaminated Invertebrate Diets.** Source: Appendix E.

Table 6-21
Mean Lipid Peroxidation (standard error in parenthesis) of Brown and Rainbow Trout Fed Invertebrate Diets Collected from the Clark Fork River

Water and Diet	Brown Trout	Rainbow Trout
0X		
Turah Bridge	1.68 (0.15)[a*]	1.39 (0.15)
Gold Creek	2.52 (0.06)[b]	1.22 (0.10)
Warm Springs	3.99 (0.72)[c]	1.52 (0.40)
1X		
Turah Bridge	1.80 (0.09)[a]	0.94 (0.07)
Gold Creek	2.84 (0.45)[a,b]	1.57 (0.23)
Warm Springs	3.85 (0.63)[b,c]	1.68 (0.51)

* Values with different letters are significantly different ($p < 0.05$).

Source: Appendix F.

Summary and Conclusions

The results of these studies demonstrate that in laboratory exposures:

- Arsenic, cadmium, copper, and lead concentrations accumulated in the tissues of trout fed contaminated invertebrate diets from the Clark Fork River.

- Water-only exposures resulted in an increase of accumulated cadmium and lead; diet-only exposures resulted in an increase of arsenic, cadmium, copper, and lead.

- Increased gut impaction, constipation, cell membrane damage (lipid peroxidation), and decreased digestive enzyme production were all observed in brown trout fed the contaminated Warm Springs and Gold Creek diets. Other physical deformations observed in the gastrointestinal tracts of brown and rainbow trout fed the contaminated diets (Warm Springs and Gold Creek) included the sloughing of intestinal mucosal cells. These deformations indicate that the reduced growth observed in these fish resulted in decreased food assimilation efficiency caused by exposure to hazardous substances (Appendix E).

Thus, a consistent pattern of tissue accumulation and physical deformations was observed in trout fed the contaminated invertebrate diets. Again, it should be noted that although many of the same injuries were not observed in rainbow trout, rainbow trout fed the contaminated Gold Creek and Warm Springs diets exhibited reduced feeding activity. This reduced feeding may explain the absence of observed physiological injuries in rainbow trout in the laboratory feeding tests.

6.4.8.3 Field Studies

Fish health assessment studies also were performed using fish collected in the field from the Clark Fork River and from two control locations.[20] These field studies, using free-ranging trout, demonstrated a similar pattern of fish health degradation as the laboratory studies. This section describes the results of these studies.

As described in Appendix F, brown trout were collected in May 1992 from the Clark Fork River near Warm Springs and near Turah Bridge, as well as from two control locations: the Big Hole River and Rock Creek. Length and weight measurements were taken in the field, and tissues of large intestine, gill, kidney, liver, pyloric caeca,[21] stomach, and stomach contents were dissected for examination and analysis. The fish health endpoints assessed using these fish were similar to those used in the laboratory analysis:

- Tissue concentrations of hazardous substances
- Histopathological examination
- Lipid peroxidation
- Autopsy assessment.

In addition, metallothionein (MT) concentrations were measured.

Tissue Concentrations of Hazardous Substances

Trout collected from the Clark Fork River near Warm Springs had significantly higher tissue concentrations than baseline conditions for copper (in gill, liver, kidney, pyloric caeca, stomach, large intestine, stomach contents, and whole fish), cadmium (gill, liver, kidney, pyloric caeca, stomach, large intestine, and stomach contents), lead (kidney, stomach, and stomach contents), and arsenic (gill, liver, kidney, and pyloric caeca) than baseline conditions (Figures 6-21 to 6-24 and Table 6-22).

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[20] A description of these studies also is presented in Appendix F, "Research Report on Injury Determination, Fishery Protocol #2," by H.L. Bergman, and in Farag et al. (in press).

[21] An extension of the small intestine in fish.

Figure 6-20. Impacted Gut in Brown Trout Fed the Warm Springs Invertebrate Diet. (Exposed test fish on left; control fish on right.) Source: Appendix E.

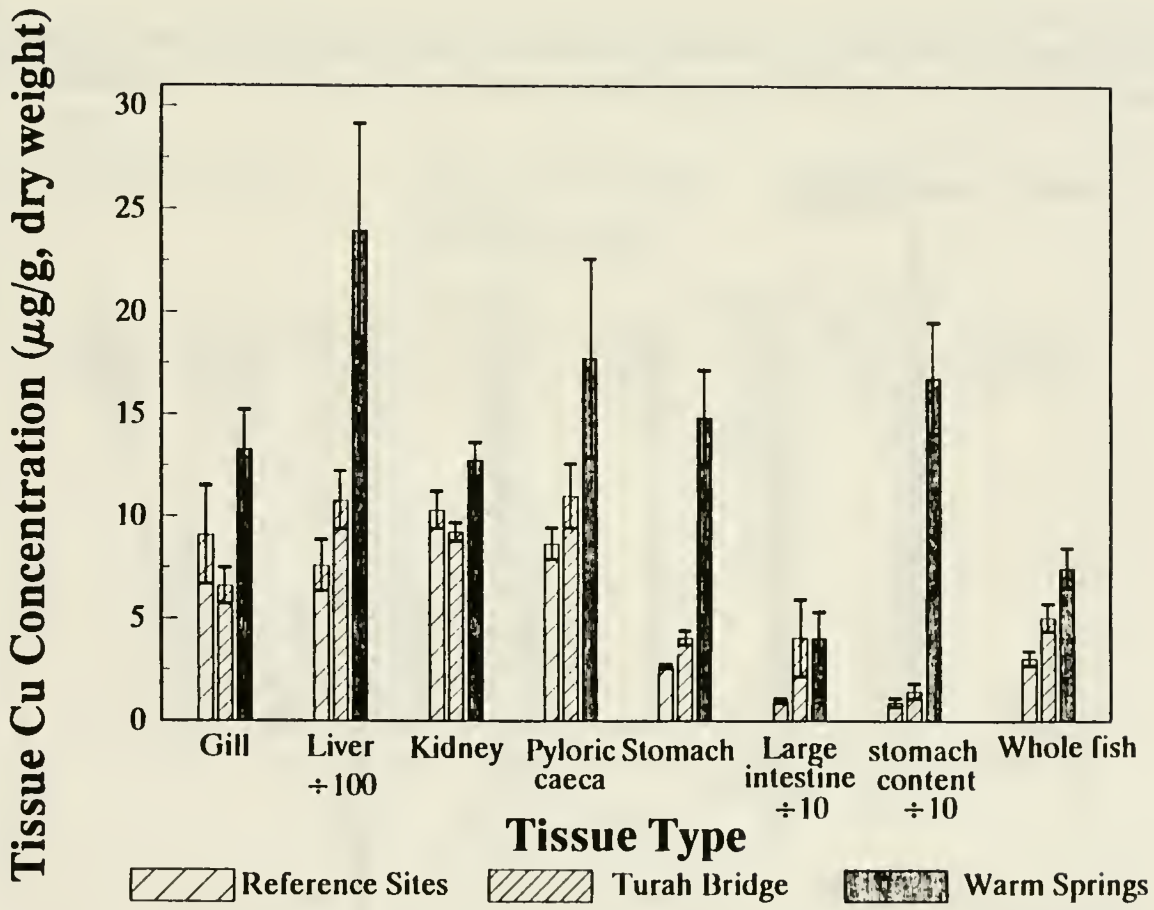

Figure 6-21. **Mean Concentrations (± 1 Std. Error) of Copper in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek).** Source: Farag et al. (in press).

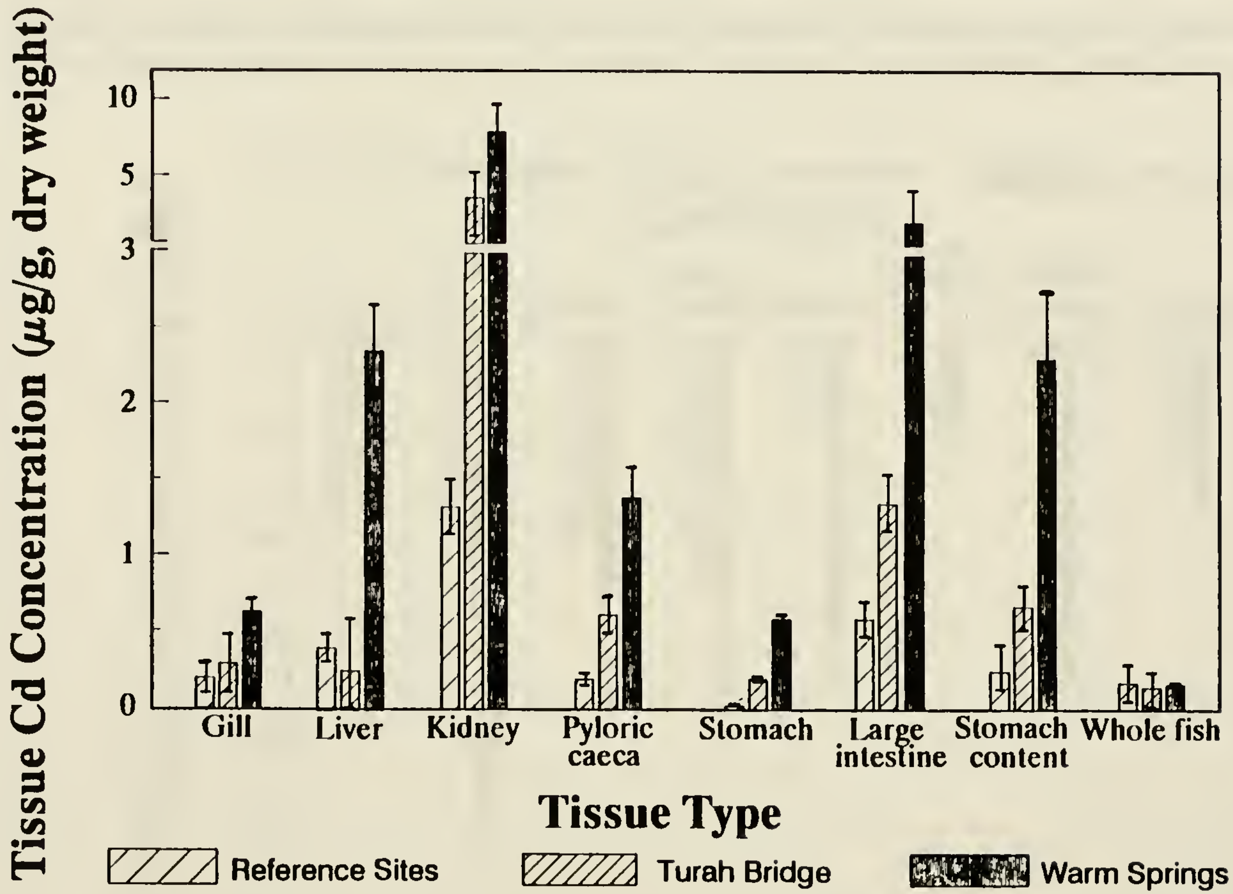

Figure 6-22. Mean Concentrations (± 1 Std. Error) of Cadmium in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek). Source: Farag et al. (in press).

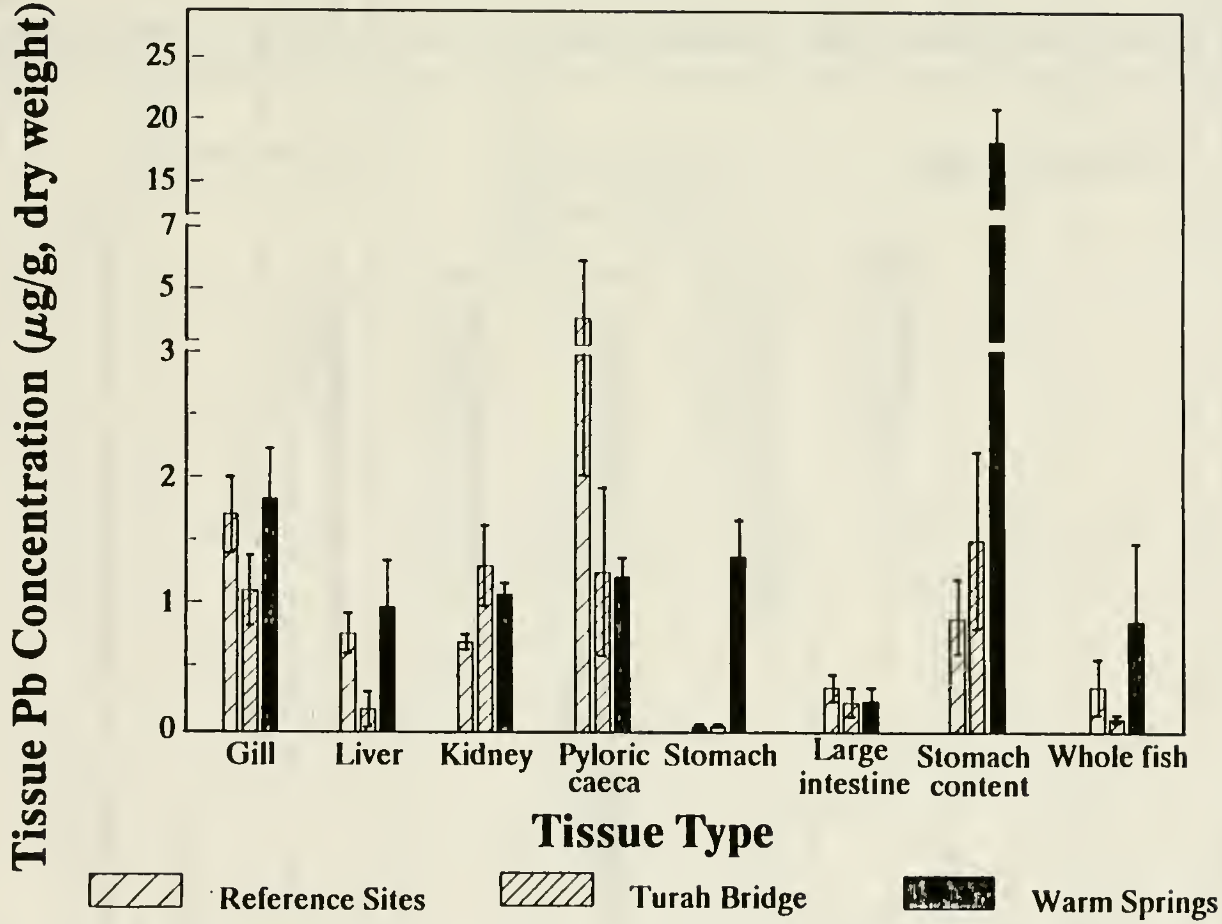

Figure 6-23. **Mean Concentrations (± 1 Std. Error) of Lead in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek).** Source: Farag et al. (in press).

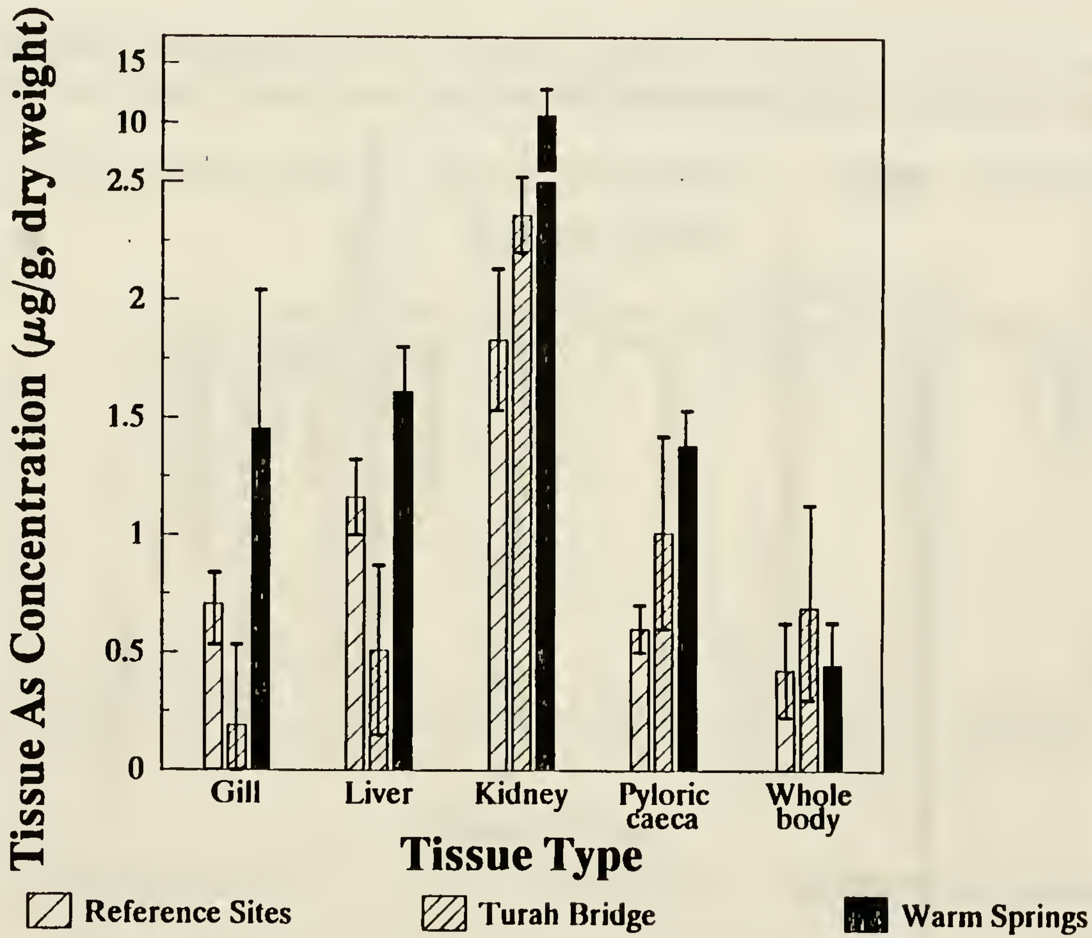

Figure 6-24. Mean Concentrations (± 1 Std. Error) of Arsenic in Field-collected Brown Trout from the Clark Fork River (Warm Springs, Turah Bridge) and a Control ("Reference") Site (Rock Creek). Source: Farag et al. (in press).

Table 6-22
Statistical Comparison of Median Concentrations of Hazardous Substances in Free-Ranging Brown Trout Collected from the Clark Fork River and from Control Rivers (Rock Creek, Big Hole River). Statistical significance denoted for $\alpha = 0.05$. "Y" indicates significantly different from baseline conditions, "YY" indicates significantly different from downstream Clark Fork River Site (Turah Bridge), "N" indicates no significant differences, "—" indicates no data.

Collection Site	Gill	Liver	Kidney	Pyloric Caeca	Stomach	Large Intestine	Stomach Contents	Whole Fish
—Copper—								
Warm Springs	Y,YY	Y,YY	Y,YY	Y	Y,YY	Y	Y,YY	Y,YY
Turah Bridge	N	Y	N	N	Y	Y	N	Y
—Cadmium—								
Warm Springs	Y,YY	Y,YY	Y,YY	Y,YY	Y,YY	Y,YY	Y,YY	N
Turah Bridge	N	Y*	Y	Y	Y	Y	Y	N
—Arsenic—								
Warm Springs	Y,YY	Y,YY	Y,YY	Y,YY	—	—	—	N
Turah Bridge	Y*	Y*	Y	N				N
—Lead—								
Warm Springs	N	N	Y	N	Y,YY	N	Y,YY	N
Turah Bridge	N	Y*	Y	N	Y	N	N	N

* Lower than control values.

In addition, trout collected from the Clark Fork River near Warm Springs also had significantly higher concentrations of hazardous substances than trout collected from the downstream Clark Fork River site near Turah Bridge for copper (gill, liver, kidney, stomach, stomach contents, and whole fish), cadmium (gill, liver, kidney, pyloric caeca, stomach, large intestine, and stomach contents), and arsenic (gill, liver, kidney, pyloric caeca).

Trout collected from the downstream Clark Fork River site near Turah Bridge had significantly higher tissue concentrations than baseline (Rock Creek and Big Hole) for copper (liver, stomach, large intestine, and whole fish), cadmium (kidney, pyloric caeca, stomach, large intestine, and stomach contents), lead (kidney and stomach), and arsenic (kidney).

These data demonstrate that free ranging trout are exposed to elevated concentrations of hazardous substances in their diets (as shown by stomach contents), and accumulate elevated concentrations of hazardous substances in their tissues.

As described in Appendix F, the copper residues measured in Clark Fork River fish are substantially higher than those reported from various locations in the United States. Schmitt and Brumbaugh (1990, as cited in Appendix F) report a national geometric mean concentration of copper in whole fish of 3.25 μg/g (dry weight), and a national 85th percentile concentration of 5.0 μg/g (dry weight). In contrast, fish collected from the Clark Fork River near Warm Springs had a mean whole body copper concentration of 6.36 μg/g (dry weight). Fish collected from the Clark Fork River near Turah Bridge had a mean whole body copper concentration of 4.26 μg/g (dry weight). Measured baseline concentrations (Rock Creek and Big Hole River combined) were 3.04 μg/g (dry weight) — approximately the same as the national mean concentration. Moreover, these copper residues were lower than those reported for fish collected from the same reaches of river in the mid-1970s. Dent (1974, as cited in Appendix F) reported whole body copper concentrations of 7.2 μg/g in the Clark Fork River downstream from Warm Springs, 7.2 μg/g near Racetrack, and 7.0 μg/g near Rock Creek.

Finally, as described in Appendix F, copper residues measured in livers from both the Warm Springs and the Turah Bridge fish exceeded liver concentrations that have been shown to impair both growth and reproduction in fish.[22] Similarly, copper residues measured in livers from the Warm Springs fish (mean of approximately 2,400 ppm, dry weight) were similar to, and somewhat greater than, those measured in the acclimated Clark Fork River brown trout during the acclimation study in which reduced growth was observed (mean of approximately 2,065 ppm, dry weight)

Histopathological Assessment

As described in Appendix F, livers of fish collected from both of the Clark Fork River sites and from the Rock Creek control site exhibited varying amounts of copper inclusions in liver cells, with the number and extent of copper inclusions being Clark Fork River/Warm Springs > Clark Fork River/Turah Bridge > Rock Creek > Big Hole River (no inclusions observed). In addition, irreversible cell damage (nuclear vacuolation of hepatocytes) was also observed, with the number and extent of liver damage being Clark Fork River/Turah Bridge > Clark Fork River/Warm Springs > Rock Creek > Big Hole River (no abnormalities observed).

Lipid Peroxidation

As shown in Figure 6-25, lipid peroxidation in large intestine, liver, and pyloric caeca of fish collected from the Clark Fork River/Warm Springs site was significantly greater than either Turah Bridge or baseline, where baseline conditions were defined by pooling the results from

[22] It should be noted that copper concentrations in livers from control site fish also exceeded this threshold. This emphasizes the conservative nature of the control sites in determining baseline and may explain why no significant growth reductions were observed in the autopsy assessments.

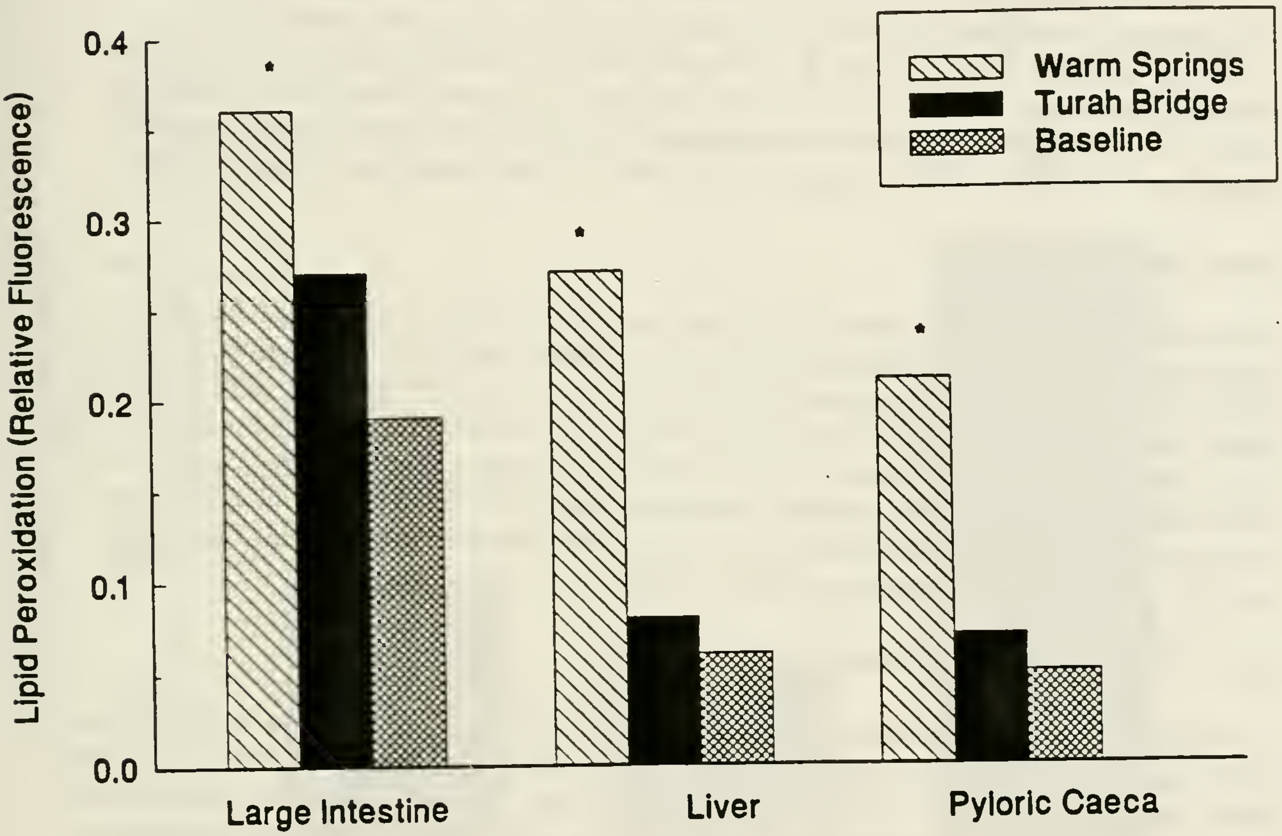

Figure 6-25. Lipid Peroxidation (Measured as Relative Fluorometric Intensity) in Brown Trout Collected from the Clark Fork River (Warm Springs and Turah Bridge Sites) versus Baseline. Baseline conditions determined from pooled data from two control sites: Big Hole River and Rock Creek. (* indicates significantly different from baseline, $p < 0.05$). Source: Appendix F.

the two control sites, Rock Creek and the Big Hole River. There were no significant differences between Turah Bridge and baseline.

Autopsy Assessment

There were no significant differences observed in any of the autopsy parameters. Although not statistically significant at the 5% level, the mean growth condition factor (KTL) [calculated as $(W \times 10^5)/L^3$, where W = weight (g) and L = length (mm)] in Warm Springs trout was lower than the mean KTL in trout from any of the other three sites. Again, the *order* of the KTLs was consistent with the degree of site contamination, with Clark Fork River/Warm Springs < Clark Fork River/Turah Bridge < Big Hole River < Rock Creek.

Metallothionein

As described previously, increased MT in fish tissue is an indicator of exposure to heavy metals and potential growth reduction injuries. The levels of MT in liver tissues of the Warm Springs brown trout were significantly higher than in the Turah Bridge, Big Hole River, or Rock Creek brown trout (Figure 6-26). The MT levels in the Warm Springs brown trout was more than two times the MT levels in each of the trout from the other three locations, and were comparable to the levels observed in the acclimation studies demonstrating growth reductions. Therefore, it is reasonable to conclude that the free-ranging Clark Fork River trout are subject to similar growth reduction injuries.

Other Health Impairment Indicators

In addition to the above indicators of physiological health impairment, Farag and Bergman (1993, as cited in Appendix F) reported scale loss in 83% of adult rainbow trout fed a diet of contaminated invertebrates collected from the Clark Fork River near the Warm Springs Ponds. Similarly, Tohtz (1992, as cited in Appendix F) observed a high rate of scale regeneration (scales regenerate after being lost) in free-ranging brown trout collected from the Clark Fork River. Scale loss, observed in both laboratory and field studies, may therefore represent a physiological impairment caused by exposure to hazardous substances. It is generally accepted that scale loss can lead to increased susceptibility to disease and parasitism which, in turn, can reduce survivability in the field (Gaines and Rogers, 1975; as cited in Appendix F).

Summary and Conclusions

Overall, the results of the fish health impairment field studies show a similar pattern of hazardous substance accumulation and resulting physiological stress as was shown in the laboratory studies. Specifically:

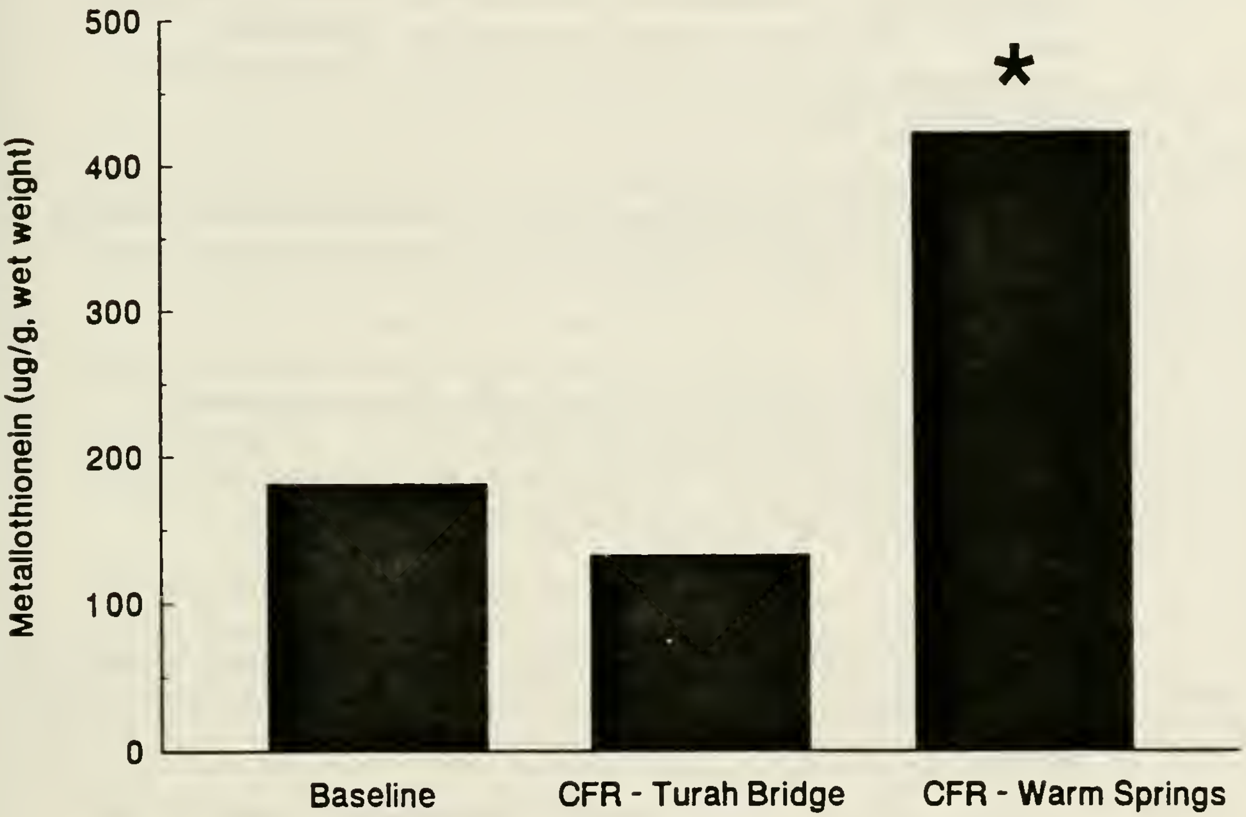

Figure 6-26. Metallothionein in Brown Trout Collected from the Clark Fork River (Warm Springs and Turah Bridge Sites) versus Baseline. Baseline conditions determined from pooled data from two control sites: Big Hole River and Rock Creek. (* indicates significantly different from baseline, $p < 0.05$).

- Free-ranging trout collected from the Clark Fork River/Warm Springs site had significantly higher tissue concentrations of copper, cadmium, lead, and arsenic than baseline conditions, as well as significantly higher tissue concentrations of copper, cadmium, lead, and arsenic than the less-contaminated downstream site near Turah Bridge. In addition, trout had significantly elevated concentrations of hazardous substances in stomach contents — documenting food-chain exposure to hazardous substances in free-ranging fish.

- Whole-body copper concentrations at the Clark Fork River/Warm Springs site exceeded the national 85th percentile concentrations. Whole-body concentrations at the Clark Fork River/Turah Bridge site exceeded national mean concentrations.

- Trout fed contaminated invertebrates from the Clark Fork River accumulated copper, arsenic, lead, and cadmium. Hazardous substance residues in these fish (whole-body) were similar to whole body residues measured in free-ranging trout.

- Damage to liver cells in fish was observed in histopathological examination of fish collected from the field. The number and extent of damaged cells appeared to correspond to the degree of contamination of the site (Clark Fork River/Warm Springs > Clark Fork River/Turah Bridge > Rock Creek). No abnormalities were observed in livers from Big Hole River Fish.

- Increased lipid peroxidation was found in organs of fish collected from the Clark Fork River/Warm Springs site and in fish fed contaminated invertebrates from the Clark Fork River. Lipid peroxidation affects the integrity of cell membranes; these changes can ultimately result in tissue damage and cell death (Halliwell and Gutteridge, 1985; as cited in Appendix F).

- Increased concentrations of metallothionein were measured in livers of fish collected from the Clark Fork River/Warm Springs site. As described previously, metallothionein induction involves a physiological "cost of acclimation" that has been associated with reduced growth.

- Scale loss was observed in both laboratory experiments (in which adult trout were fed contaminated Clark Fork River invertebrates) and in free-ranging fish collected from the Clark Fork River. Scale loss can decrease resistance to disease and parasitism, and reduce survivability in the field.

- A reduction, although not statistically significant at the 5% level, was found in the growth condition factor of fish collected from the Clark Fork River/Warm Springs site relative to baseline. However, the measured condition factors

varied with increasing contamination, with Clark Fork River/Warm Springs < Clark Fork River/Turah Bridge < Big Hole River < Rock Creek. Similarly, Tohtz (1992, as cited in Appendix F) found that 4,5, and 6 age-class brown trout from below Warm Springs were significantly smaller ($p < 0.05$) than fish from the Big Hole River, (the growth reductions observed in 1981 and 1989 were not statistically significant at the 5% level). Although these measured growth reductions were not found consistently to be statistically significant, they are consistent with the observed pattern of growth reductions observed in the laboratory feeding experiments described in Section 6.4.6 and by other researchers.

- The data collected from laboratory and field studies indicate that reduced growth has resulted from exposure to hazardous substances. These data include: growth reductions in the laboratory feeding studies, observed digestive system degeneration in the feeding studies (including gut impaction and intestinal/pancreatic cell degeneration), increased lipid peroxidation in both laboratory and field studies, increased metallothionein in field studies, copper residues in both laboratory and field-collected trout at concentrations shown to cause growth reductions, reduced growth condition factors in field-collected trout, and size reductions in field-collected fish. The overall weight of evidence — and the consistent pattern that arises from the data — supports the conclusion that trout growth has been impaired. This conclusion is consistent with the results of controlled laboratory studies in which growth reductions were caused by both sub-lethal water exposures and by food-chain exposures to contaminated Clark Fork River invertebrates.

The results of the fish health studies, including both laboratory and field assessments, therefore present a consistent pattern of (1) exposure to hazardous substances, (2) cell damage (including digestive system degeneration, lipid peroxidation, and liver abnormalities), (3) scale loss, and (4) reduced growth. These health impairment injuries contribute to reduced survivability of trout in the Clark Fork River.

6.4.9 Injury Determination Summary

The results of injury determination for fishery resources include the following conclusions:

- Injuries to fish that have resulted from exposure to hazardous substances in surface water and in food-chains include death, behavioral avoidance, reduced growth, and health impairment.

- Death has been confirmed in fish kills, *in situ* bioassays, and controlled laboratory studies.

- Fish kills have occurred frequently in the Clark Fork River.

- *In situ* bioassays have demonstrated significant mortality in the Clark Fork River and in Silver Bow Creek. The results of the fish kills and *in situ* bioassays present clear evidence that ambient concentrations of hazardous substances in Silver Bow Creek and the Clark Fork River cause lethal injuries to trout.

- Laboratory studies demonstrated that exposure to acute pulses of elevated hazardous substances similar to those documented in the Clark Fork River causes significant trout mortality. Small trout (fry) were more sensitive than larger trout (juveniles).

- Standard laboratory acute toxicity studies demonstrated that short-term continuous exposures to copper, cadmium, lead, and zinc at concentrations documented in Silver Bow Creek and the Clark Fork River causes significant trout mortality. Small trout (fry) were more sensitive than larger trout (juveniles).

- Laboratory studies demonstrated that both brown and rainbow trout avoid hazardous substances at concentrations regularly documented in Silver Bow Creek and the Clark Fork River. These studies also determined that rainbow trout are more sensitive than brown trout in avoiding hazardous substances.

- Behavioral avoidance can limit the immigration of fish ("recruits") from tributaries into Silver Bow Creek and the Clark Fork River, and can cause emigration to tributaries. Together, these effects contribute to effects on resident populations.

- Laboratory studies documented that food-chain pathways injure trout. Fish fed diets of contaminated Clark Fork River invertebrates demonstrated increased mortality, decreased growth, and health impairment.

- Reduced growth, an indicator of compromised survivability in the field, was documented in controlled laboratory studies. The weight of evidence indicates that growth has been reduced in free-ranging fish collected from the Clark Fork River.

- A consistent pattern of metal accumulation in tissues, degeneration of digestive cells (likely leading to reduced growth), cellular damage, and synthesis of metal-binding proteins required to detoxify/excrete metals (production of which entails a metabolic cost that has been shown to reduce growth and long-term

survivability) was observed in both laboratory-exposed and free-ranging organisms from the Clark Fork River.

The above conclusions all indicate the presence of multiple and pervasive injuries to resident fish of Silver Bow Creek and the Clark Fork River from hazardous substances released from numerous sources in Butte and Anaconda. As described below, these multiple injuries act together to cause a single harm: reductions in trout populations.

6.5 INJURY QUANTIFICATION

The preceding sections have demonstrated that fish have been injured throughout Silver Bow Creek and the Clark Fork River. This section demonstrates that trout populations have been eliminated completely from Silver Bow Creek, and that trout populations in the Clark Fork River have been substantially reduced. Thus, the injuries to fisheries resources documented in the preceding sections of this chapter are quantified in terms of overall reductions in trout populations in Silver Bow Creek and the Clark Fork River relative to baseline conditions.

This section contains three sub-sections. Section 6.5.1 describes the process of injury quantification. Section 6.5.2 summarizes the methodologies used to quantify fish injury in this report. In Section 6.5.3, injuries to the fisheries resource in Silver Bow Creek and the Clark Fork River are quantified in terms of trout population reductions.

6.5.1 Injury Quantification

43 CFR § 11.71 (l) presents guidelines for quantifying injury to biological resources such as fisheries. These guidelines provide the following:

- The extent to which the injured biological resource differs from baseline should be determined by analysis of the population . . . levels [43 CFR § 11.71 (l)(1)].

- Population changes...should be based upon species . . . that represent broad components of the ecosystem..., that are especially sensitive to the hazardous substance . . ., [or] that provide especially significant services [43 CFR § 11.71 (l)(2)(i-iii)].

- Population measurement methods should . . . provide numerical data that will allow comparison between assessment area data and control area or baseline data . . ., provide data that will be useful in planning restoration or replacement efforts . . ., and allow correction, as applicable, for factors such as dispersal of organisms in or out of the assessment area...and other potential systematic biases in the data collection [43 CFR § 11.71 (l)(4)(i-iii)].

- When estimating population differences in animals, . . . estimation techniques appropriate to the species and habitat shall be used [43 CFR § 11.71 (l)(5)].

Trout populations in Silver Bow Creek and the Clark Fork River are quantified relative to baseline populations in control areas. As described previously, the assessment measured *trout* populations because of the use and nonuse services provided by trout. All population measurements were performed using accepted techniques in fisheries biology. Thus, the injury to fisheries in the upper Clark Fork River Basin has been quantified in accordance with these regulations.

6.5.2 Methodologies for Quantifying Fisheries Injury

Injuries to trout populations were quantified in terms of reductions in the quantity of the resource, trout populations, relative to baseline conditions [43 CFR § 11.72]. Where historical data do not provide adequate information to define baseline, or a substantial amount of time has passed since the release of hazardous substances began (both of these conditions apply to the assessment area), baseline data are collected from control areas [43 CFR § 11.72 (d)]. A control area is defined as an area or resource unaffected by the discharge of the hazardous substance under investigation and one that is selected for its comparability to the assessment area or resource [43 CFR § 11.14 (i)].

Injuries were quantified as differences between trout population densities in Silver Bow Creek and the Clark Fork River relative to similar control sites using electrofishing techniques and quantitative direct observation surveys. Both techniques are standard and widely accepted methods of quantifying salmonid populations (e.g., Keenleyside, 1962; Drew et al., 1976; Keast, 1977; Bachman, 1982; Barans, 1982; Nielsen and Johnson, 1983; Schill and Griffith, 1984; Hicks and Watson, 1985; Hankin and Reeves, 1988; Zubik and Fraley, 1988; Thurow, 1992). A detailed account of fisheries injury quantification methodologies is provided in Appendices G and H.[23] In general, the approach used was based on the following steps:

- Classify Silver Bow Creek and the Clark Fork River in terms of geology, morphology, and habitat conditions.

[23] "Assessment of Injury to Fish Populations: Clark Fork River NPL Sites, Montana," by Don Chapman Consultants, Inc., and "Supplement to Assessment of Injury to Fish Populations: Clark Fork River NPL Sites, Montana, by Don Chapman Consultants, Inc.

- Select control[24] sites for comparison to Silver Bow Creek and the Clark Fork River sites using objective criteria.

- Compare water quality characteristics between test and control reaches.

- Measure fish abundance and available habitat at control sites to quantify baseline conditions in terms of trout density and biomass.

- Measure fish abundance and habitat at sites in Silver Bow Creek and the Clark Fork River to quantify population injuries (trout density and biomass).

- Quantify injury in terms of significant differences from baseline.

A brief overview of these methods is presented below.

6.5.2.1 Site Classification and Selection

Site Classification

As described in Appendix G, an objective hierarchical classification approach was used to select matched test and control sites that provide fish habitat similar to that of the Clark Fork River and Silver Bow Creek. The purpose of the classification approach was to account for possible sources of trout population differences between sites related to land uses, trout habitat, and stream flows, thereby isolating population changes caused by hazardous substances. The classification approach matched geologic and morphologic features that affect fish populations, including major geology, valley shape, hydrologic features (collectively referred to as valley bottom type), and channel and stream bank condition (state type) of control sites to those conditions found at test sites (Table 6-23). For example, between-drainage variability of fish habitat variables related to climate and geography, such as season length and timing, water levels, and water temperature are minimized by selecting control sites in proximity to the Clark Fork Basin and that drain watersheds of similar elevation ranges and valley types. Similarly, between-drainage variability in dominant size fraction of weathering products and thus the dominant size of stream bottom substrate is reduced by selecting sites with similar geology, valley bottom type, shape, and gradient. Variability in habitat conditions related to water volume and velocity was minimized by measuring available habitat (see description below) and evaluating fish abundance based on

[24] Appendices G and H use the term "reference" sites to denote sites that have similar attributes to impact sites, serve as controls per the DOI regulations, but are not "laboratory controls." For the purposes of this section, the term "control" is employed per DOI regulations; the term has equivalent meaning to the term "reference" as employed in Appendices G and H.

Table 6-23
Hierarchical Classification System Used to Match Control Sites for the Clark Fork River and Silver Bow Creek

Hierarchical Level	Description
Ecoregion	An area determined by similar land-surface form, potential natural vegetation, land-use and soil.
Geologic district	A portion of an ecoregion with relatively homogeneous parent materials, distinguished from surrounding districts by structure, degree of weathering, dominant size-fractions of weathering products and water-handling characteristics; includes both uplands and bottomlands.
Landtype association	A part of a geologic district that is distinguished by a dominant geomorphic mechanism (e.g., glacial, fluvial, alluvial, lacustrine); includes both uplands and bottomlands.
Landtype	A portion of a landtype association distinguished by form and position, corresponding with associations of soils and plant communities.
Valley-bottom type	A subset of the valley-bottom landtype distinguished by form, structure, and the manner in which water and sediments move through the system; they are generally distributed in a predictable manner along the elevational gradient of watersheds.
State type	A part of the valley-bottom type distinguished by the condition of the stream and its banks (e.g., eroded banks, laid-back banks, channelized, braided).

Source: Appendix G.

available habitat. Thus, by controlling for land use and trout habitat, any observed trout population differences between sites are caused by hazardous substances.

Maps, aerial photographs, and field observations were used to identify ecologic, geologic, geomorphic, hydrologic, and stream bank condition characteristics. Using the hierarchical approach the Clark Fork River and Silver Bow Creek were classified from the top (ecoregion) level down, therefore accounting for variance at each subsequent level of classification. The Clark Fork River and Silver Bow Creek were then partitioned into discrete segments based on the classification approach. These segments then were divided into reaches at confluences of principal tributaries (defined as contributing more than 25% of the mean annual discharge). A total of 10 reaches, 6 in the Clark Fork River and 4 in Silver Bow Creek, were defined. The reaches were then divided into discrete state types to yield a total of 39 discrete state-reach segments (26 in the Clark Fork River, 13 in Silver Bow Creek).

Following classification of Silver Bow Creek and the Clark Fork River into distinct state-reach segments, corresponding control stream segments that had similar ecologic, geologic, geomorphic, hydrologic, and state type characteristics were identified using the classification approach. These control rivers included two tributaries of the Clark Fork (Rock Creek and Flint Creek), as well as the Big Hole River, the Ruby River, the Beaverhead River, and Bison Creek.

Selection of Sampling Sites

As described in Appendix G, following classification of the Clark Fork River and Silver Bow Creek into discrete state-reach segments and subsequent matching with appropriate control segments, specific state-reach segments were selected for sampling. Generally, one of each state type within each reach was sampled. However, several state-reach types were not sampled because they constituted a very small proportion of the total reach length (see Appendix G). In addition, reach 8 (in Silver Bow Creek) was not sampled because it is a small reach (approximately 1.5 miles in length) that is similar to reach 9.

A total of 19 state-reach segments were sampled in the assessment area. Four reaches in Silver Bow Creek were sampled; these reaches were matched to four of the control reaches — two in Bison Creek, and one each in the Ruby River and the Big Hole River (Table 6-24 and Figure 6-27). Fish population density and biomass was measured at 15 Clark Fork River reaches between Warm Springs Ponds and the Milltown Reservoir and 15 corresponding control sites in the Big Hole, Beaverhead, and Ruby Rivers, as well as Flint and Rock Creeks (Table 6-24 and Figure 6-27).

Comparison of Impact and Control Sites

Overall, the control site selection for this study complied with the DOI guidelines [43 CFR § 11.72 (d)]:

- *One or more control areas shall be selected based on similarity to the assessment area and lack of exposure to the discharge or release.* Similarity between impact and control areas was maintained by applying the hierarchical classification approach. Impact sites in Silver Bow Creek and the Clark Fork River had statistically significantly greater concentrations of hazardous substances than the matched control sites (Chapter 4.0).

- *Where the release occurs in a stream, at least one control area upstream of the assessment area shall be included, unless local conditions indicate that the area is inapplicable as a control area.* As a result of mining and mineral-processing operations in the Butte area, headwaters of Silver Bow Creek and the Clark Fork River (the headwater of which is Silver Bow Creek) have been

Table 6-24
Clark Fork River and Silver Bow Creek Fish Population Sampling Areas and Matching Control Sites

Test Site (Reach, State Type)	Control Site (Reach, State Type)
Clark Fork River Sample Site 1 (1, 7/3)	Rock Creek Sample Site 3a (1, 3)
Clark Fork River Sample Site 2 (1, 4/5)	Rock Creek Sample Site 3b (1, 3)
Clark Fork River Sample Site 3 (1, 3/5)	Rock Creek Sample Site 3a (1, 3)
Clark Fork River Sample Site 4 (2, 3)	Rock Creek Sample Site 3b (1, 3)
Clark Fork River Sample Site 5 (2, 4)	Rock Creek Sample Site 4 (1, 10)
Clark Fork River Sample Site 6 (2, 2)	Rock Creek Sample Site 2 (1, 2)
Clark Fork River Sample Site 7 (3, 4)	Big Hole River Sample Site 5a (5, 10)
Clark Fork River Sample Site 8 (3, 3)	Big Hole River Sample Site 4 (5, 3)
Clark Fork River Sample Site 9 (4, 3)	Big Hole River Sample Site 3 (5, 3/9)
Clark Fork River Sample Site 10 (4, 4)	Big Hole River Sample Site 5b (5, 10)
Clark Fork River Sample Site 11 (5, 5)	Big Hole River Sample Site 2 (4, 10)
Clark Fork River Sample Site 12 (6, 2d)	Flint Creek Sample Site 1a (1, 2)
Clark Fork River Sample Site 13 (6, 4)	Ruby River Sample Site 1 (1, 4)
Clark Fork River Sample Site 14 (6, 2u)	Flint Creek Sample Site 1b (1, 2)
Clark Fork River Sample Site 15 (6, 1/2)	Beaverhead River Sample Site 1 (2, 1/2)
Silver Bow Creek Sample Site 1 (7, 2)	Ruby River Sample Site 2 (3, 2)
Silver Bow Creek Sample Site 2 (7, 4/6)	Big Hole River Sample Site 1 (1, 3/9)
Silver Bow Creek Sample Site 3 (9, 4/6)	Bison Creek Sample Site 1 (1, 3/2)
Silver Bow Creek Sample Site 4 (10, 3/6)	Bison Creek Sample Site 2 (3, 3/2)

Note: Sample site numbers are from downstream to upstream. Approximate sampling locations may be found in Figure 6-27.

Source: Appendix G.

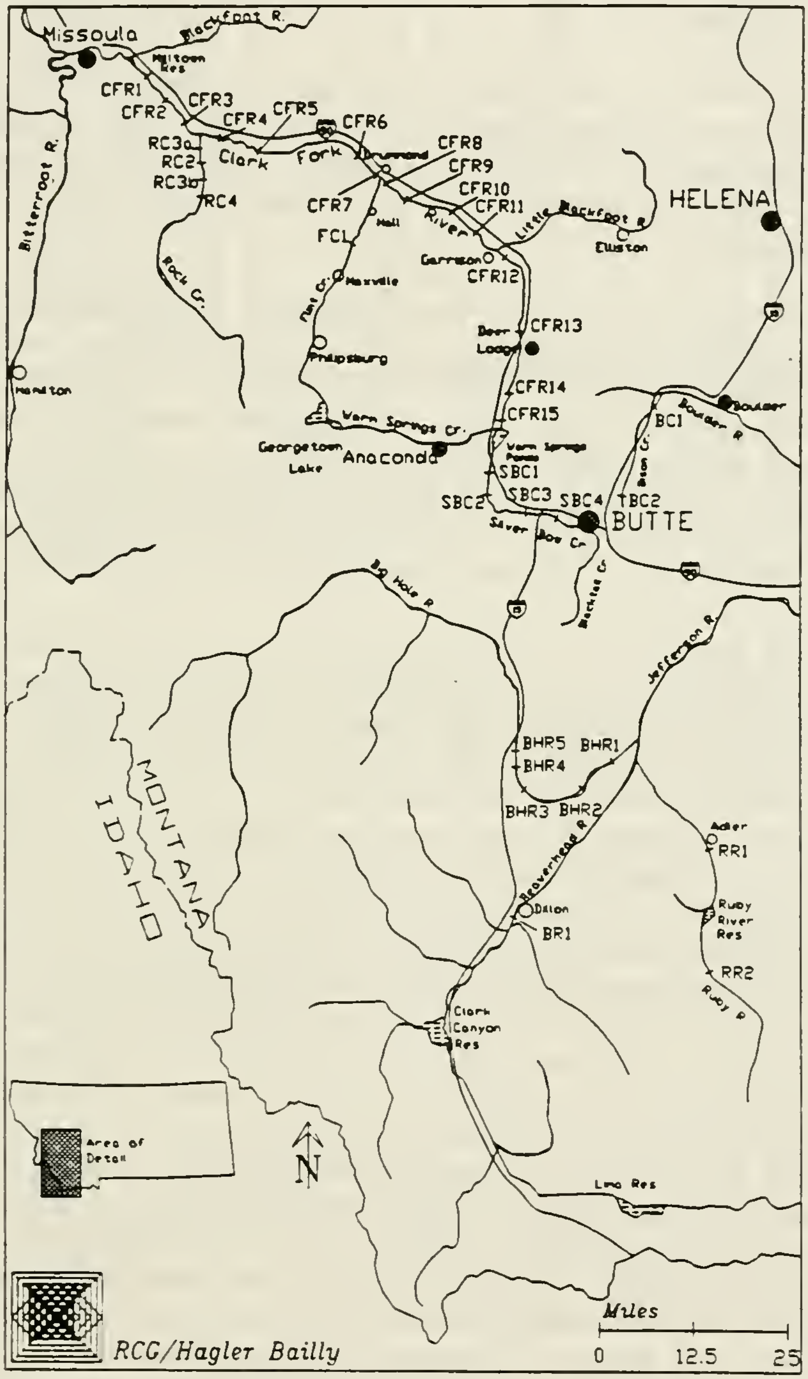

Figure 6-27. Approximate Fish Population Sampling Locations for Test and Control Streams. CFR = Clark Fork River; SBC = Silver Bow Creek; RC = Rock Creek; FC = Flint Creek; BC = Bison Creek; BHR = Big Hole River; RR = Ruby River; BR = Beaverhead River.

contaminated with hazardous substances. Therefore, their use as control areas is inappropriate.

- *Comparability of each control and the assessment area shall be demonstrated to the extent technically feasible.* Control and assessment area sites were selected using a hierarchical classification approach that minimized between-river variability. As described below, control and assessment area sites were comparable.

Table 6-25 presents a comparison of the climatic, geological, geomorphic, and hydrologic characteristics of the Silver Bow Creek/Clark Fork River reaches and the matching control reaches. It can be seen from the table that habitat characteristics of Clark Fork River and Silver Bow Creek reaches were similar to the control reaches. Generally all test and control sites were dominated by rubble and gravel substrate. Generally, neither test nor control sites had abundant wood or canopy cover. Test and control sites generally exhibited greater than 60% bank cover. These results support the conclusion that the aquatic attributes of the Clark Fork River and Silver Bow Creek and their respective control sites are similar (Appendix G).

In addition to habitat characteristics, basic water quality characteristics (dissolved oxygen, dissolved organic carbon, temperature, nitrate/nitrogen, conductivity, hardness, alkalinity) were compared between the impact and control reaches (as shown in Chapters 3.0 and 4.0, concentrations of hazardous substances in bed sediments and surface water are significantly greater in impact sites). Dissolved oxygen, dissolved organic carbon, and temperatures generally were similar at impact and control sites (see Appendix A). Table 6-26 presents summary data for pH, conductivity (specific conductance), hardness, nitrate/nitrogen, alkalinity, and temperature for paired assessment and control reaches. pH values generally were similar for impact and control reaches (mean values ranged from 7.8 to 8.2 for all reaches). Conductivity, hardness, alkalinity, and nitrate-nitrogen tended to be higher in the Clark Fork River and in Silver Bow Creek than in corresponding control reaches (except for the Ruby River, which is very similar to the Clark Fork River in conductivity and hardness). Increased hardness and conductivity (and possibly nitrate) in the Clark Fork River are, at least in part, a function of the many years of lime (calcium) treatment — still ongoing — to remove metals from Silver Bow Creek at the Warm Springs ponds. This lime treatment contributes substantial loadings of calcium that, in turn, are reflected in increased hardness and conductivity (and algal productivity). More importantly, it should be noted that increased hardness, conductivity, alkalinity, and nitrate often have been correlated with higher trout populations (e.g., Beyerle and Cooper, 1960; McFadden and Cooper, 1962; Hynes, 1970; O'Conner and Power, 1976; Binns and Eiserman, 1979; Scarnecchia and Bergersen, 1987; Larscheid and Hubert, 1992). Therefore, the comparisons between impact and control reaches are conservative and would tend to underestimate any observed differences in trout populations between the assessment area and the control sites.

Table 6-25
Comparison of Climatic, Geologic, Geomorphic, and Hydrologic Characteristics Between Test and Control Streams

Character	Reach 1 Clark Fork Sites 1-3	Reach 1 Rock Creek Sites 3a & 3b	Reach 2 Clark Fork Sites 4-6	Reach 1 Rock Creek Sites 2, 3b & 4	Reach 3 Clark Fork Sites 7 & 8	Reach 5 Big Hole Sites 4 & 5a
Ecoregion	Northern Rockies	Northern Rockies	Northern Rockies	Northern Rockies	Mont. valley & foothill prairie	Mont. valley & foothill prairie
Geologic Type	Resistant sedimentary	Resistant sedimentary	Resistant sedimentary	Resistant sedimentary	Soft sedimentary	Soft sedimentary
Landtype Association	Fluvial lands	Fluvial lands	Fluvial lands	Fluvial lands	Alluvial lands	Alluvial lands
Valley-bottom Type	Meta-sedimentary canyon	Meta-sedimentary canyon	Meta-sedimentary canyon	Meta-sedimentary canyon	Sedimentary valley	Sedimentary valley
Lower & Upper Elevations (ft)	3,255-3,499	3,499-3,980	3,499-3,951	3,499-3,980	3,890-3,954	4,850-5,060
Valley Grade (%)	0.30	0.70	0.20	0.70	0.30	0.32
Stream Grade (%)	0.28	0.65	0.23	0.65	0.26	0.28
Dominant Substrate	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel
Vegetation	Cottonwoods	Cottonwoods	Cottonwoods	Cottonwoods	Cottonwoods	Cottonwoods
Mean Discharge (cfs)	1,071	556	864	556	889	1,153

Source: Appendix G.

Table 6-25 (cont.)
Comparison of Climatic, Geologic, Geomorphic, and Hydrologic Characteristics Between Test and Control Streams

Character	Reach 4 Clark Fork Sites 9 & 10	Reach 5 Big Hole Sites 3 & 5b	Reach 5 Clark Fork Site 11	Reach 4 Big Hole Site 2	Reach 6 Clark Fork Site 15	Reach 2 Beaverhead Site 1
Ecoregion	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie
Geologic Type	Soft sedimentary	Soft sedimentary	Soft sedimentary	Soft sedimentary	Alluvium	Alluvium
Landtype Association	Alluvial lands	Alluvial lands	Alluvial lands	Alluvial lands	Alluvial lands	Alluvial lands
Valley-bottom Type	Sedimentary valley	Sedimentary valley	Sedimentary canyon	Sedimentary canyon	Alluvial basin	Alluvial basin
Lower & Upper Elevations (ft)	3,890-3,954	4,850-5,060	4,200-4,336	4,822-4,850	4,336-4,790	4,698-5,072
Valley Grade (%)	0.30	0.32	0.31	0.23	0.33	0.32
Stream Grade (%)	0.26	0.28	0.29	0.22	0.20	0.20
Dominant Substrate	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel	Gravel/sand
Vegetation Type	Cottonwoods	Cottonwoods	Cottonwoods	Cottonwoods	Willow/hay	Willow/hay
Mean Discharge (cfs)	594	1,161	594	1,153	303	396

Source: Appendix G.

Table 6-25 (cont.)
Comparison of Climatic, Geologic, Geomorphic, and Hydrologic Characteristics Between Test and Control Streams

Character	Reach 6 Clark Fork Sites 12-14	Reach 1 Flint Creek Sites 1a & 1b	Reach 1 Ruby River Site 1	Reach 7 Silver Bow Sites 1 & 2	Reach 1 Big Hole Site 1	Reach 3 Ruby River Site 2
Ecoregion	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie	Mont. valley & foothill prairie
Geologic Type	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
Landtype Association	Alluvial lands	Alluvial lands	Alluvial lands	Alluvial lands	Alluvial lands	Alluvial lands
Valley-bottom Type	Alluvial basin	Alluvial basin	Alluvial basin	Alluvial basin	Alluvial basin	Alluvial basin
Lower & Upper Elevations (ft)	4,336-4,790	3,954-4,295	4,636-5,240	4,790-5,106	4,605-4,770	5,400-5,840
Valley Grade (%)	0.33	0.77	0.51	0.57	0.33	0.55
Stream Grade (%)	0.20	0.60	0.26	0.49	0.27	0.33
Dominant Substrate	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel	Rubble/gravel
Vegetation Type	Willow/hay	Willow/hay	Willow/hay	Tailings	Cottonwoods/ hay	Willow/hay
Mean Discharge (cfs)	303	221	199	148	1,161	220

Source: Appendix G.

Table 6-25 (cont.)
Comparison of Climatic, Geologic, Geomorphic, and Hydrologic Characteristics Between Test and Control Streams.

Character	Reach 8 Silver Bow no sites selected	Reach 1 Bison Creek no sites selected	Reach 9 Silver Bow Site 3	Reach 1 Bison Creek Site 1	Reach 10 Silver Bow Site 4	Reach 3 Bison Creek Site 2
Ecoregion	Mont. valley & foothill prairie	Northern Rockies	Mont. Valley & foothill prairie	Northern Rockies	Mont. valley & foothill prairie	Northern Rockies
Geologic Type	Volcanic	Volcanic	Volcanic	Volcanic	Alluvial	Alluvial
Landtype Association	Fluvial lands	Fluvial lands	Fluvial lands	Fluvial lands	Alluvial lands	Alluvial lands
Valley-bottom Type	Volcanic canyon	Volcanic canyon	Volcanic canyon	Volcanic canyon	Alluvial basin	Alluvial basin
Lower & Upper Elevations (ft)	5,106-5,139	5,518-5,720	5,139-5,254	5,518-5,720	5,254-5,440	6,200-6,350
Valley Grade (%)	0.62	0.86	0.71	0.86	0.34	0.29
Stream Grade (%)	0.58	0.70	0.66	0.70	0.31	0.19
Dominant Substrate	Rubble/gravel	Rubble/gravel	Rubble/sand	Rubble/sand	Sand	Sand
Vegetation Type	Tailings	Willow	Tailings	Willow	Tailings	Willow/hay
Mean Discharge (cfs)	NA	NA	NA	NA	24	NA

Source: Appendix G.

Table 6-26
Comparison of Water Quality Characteristics between Test and Control Streams[1]

Test and Control Reach Pair[2]	pH	Specific Conductance (umhos at 25^0 C)	Hardness (mg/l as $CaCO_3$)	Nitrate Nitrogen[3] (mg/l as N)	Alkalinity[4] (mg/L)	Temperature (°C)[5]	
	Avg	Avg	Avg	Avg	Avg	Max	Avg
Test Reach 1/Clark Fork (Turah)	7.9	288	125	55	99	---	---
Control Reach 1/Rock Creek (mouth)	8.1	113	41	15	49	22.9	18.1
Test Reach 2/Clark Fork (Beavertail)[6,7]	7.9	480	223	78	---	26.2	21.6
Test Reach 2/Clark Fork (Bearmouth)[7]	8.0	488	226	---	---	26.2	21.6
Control Reach 2/Rock Creek (Stonehenge)[8]	8.1	102	39	15	---	23.2	19.2
Test Reach 4/Clark Fork (Gold Creek)[9]	8.0	429	187	---	114	24.9	20.8
Control Reach 5/Big Hole (Kalsta)	7.9	123	41	---	---	23.9	19.6
Test Reach 6/Clark Fork (Deer Lodge)[10]	7.9	533	236	184	128	26.7	20.6
Control Reach 1/Ruby River (below Reservoir)	8.2	631	296	---	---	22.1	18.7
Control Reach 1/Flint Creek (below Douglas Cr)[11]	8.1	250	108	58	116	21.9	17.2
Test Reach 10/Silver Bow Creek	7.8	462	153	---	---	---	---
Control Reach 3/Bison Creek	8.0	109	30	---	---	---	---

1 pH, specific conductance, hardness data collected by NRDLP in Spring, 1992 (Appendix A). Water temperature data collected by NRDLP in Summer, 1994 (see Appendix A).
2 No water quality data collected for Clark Fork Reaches 3 and 5, and Silver Bow Creek Reaches 7 and 9.
3 Nitrate data collected by MDHES and USGS (period of record July 1989 through June 1991).
4 Data based on eight samples collected by USGS between March, 1993 and May, 1994 (USGS, 1993, 1994).
5 Average is average daily maximum temperature throughout comparable monitoring timeframes for test and control sites (Appendix A).
6 No water quality data collected for the "match" control site. For comparative purposes, Rock Creek near mouth is the closest match site.
7 Water temperature data collected just upstream of Rock Creek (Appendix A).
8 For comparative purposes, nitrate data are those collected at Reach 1/Rock Creek.
9 Water temperature data collected near Jens (Appendix A).
10 Water temperature data collected upstream of Racetrack Creek (Appendix A).
11 Nitrate data collected near New Chicago.

6.5.2.2 Habitat and Fish Population Measurements

Fish population sampling sites were selected by dividing test and control reaches into 100-meter sections (defined as "sites" in Appendix G). Four sites within each state type were randomly selected for measurement of trout density and biomass. One of the four 100-meter sites was then selected for measurement of microhabitat variables[25] and for Physical Habitat Simulation (PHABSIM) modeling. Microhabitat data were collected by establishing 30 cross-sectional transect lines at the site. The physical habitat modeling enabled the comparisons of trout densities and biomass between test and control sites to be normalized for habitat and flow differences. The normalized habitat data from PHABSIM provided units of weighted usable area (WUA) of fish habitat in each river reach. Fish densities were thus expressed both as the number or biomass of fish per WUA at summer flows, and as numbers or biomass of fish per unit surface area.

Trout populations were counted in each designated stream section using either direct underwater observation (snorkeling) or electrofishing. As noted above, underwater observation by snorkeling has been shown to be an unbiased census technique under appropriate conditions (e.g., Schill and Griffith, 1984; Hillman et al., 1992). All trout greater than 1" in length were counted in each 100-meter stream segment. Electrofishing was used in rivers where poor water clarity precluded the use of snorkeling, as well as for validating the snorkel estimates of fish populations.

6.5.3 <u>Fisheries Injury</u>

1991 Sampling Data

Trout (this includes rainbow and brown trout, adults and juveniles) were significantly more abundant ($p < 0.001$) in control reaches than in impacted reaches in the Clark Fork River (Figure 6-28). Indeed, more trout were observed (trout/hectare) in control reaches than in the assessment area for all 15 reaches in the Clark Fork River and all four reaches in Silver Bow Creek.

In Silver Bow Creek, no trout were observed at any of the four test sites on the creek; these results agree with previous investigations documenting the complete absence of trout in Silver Bow Creek (Table 6-27). By contrast, trout densities at matching controls ranged from a low of 34 trout per hectare to a high of 558 trout per hectare. Brown, rainbow, and brook trout were all observed at Silver Bow Creek control reaches. In addition, some control sites were

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[25] Microhabitat variables measured were: channel width, wetted perimeter width, riffle width, run width, pool width, pool rating, bank angle, average and thalweg depth, substrate, bank cover, vegetative overhang, canopy cover, bank alteration, woody debris, sun arc, and bank undercut (Appendix G).

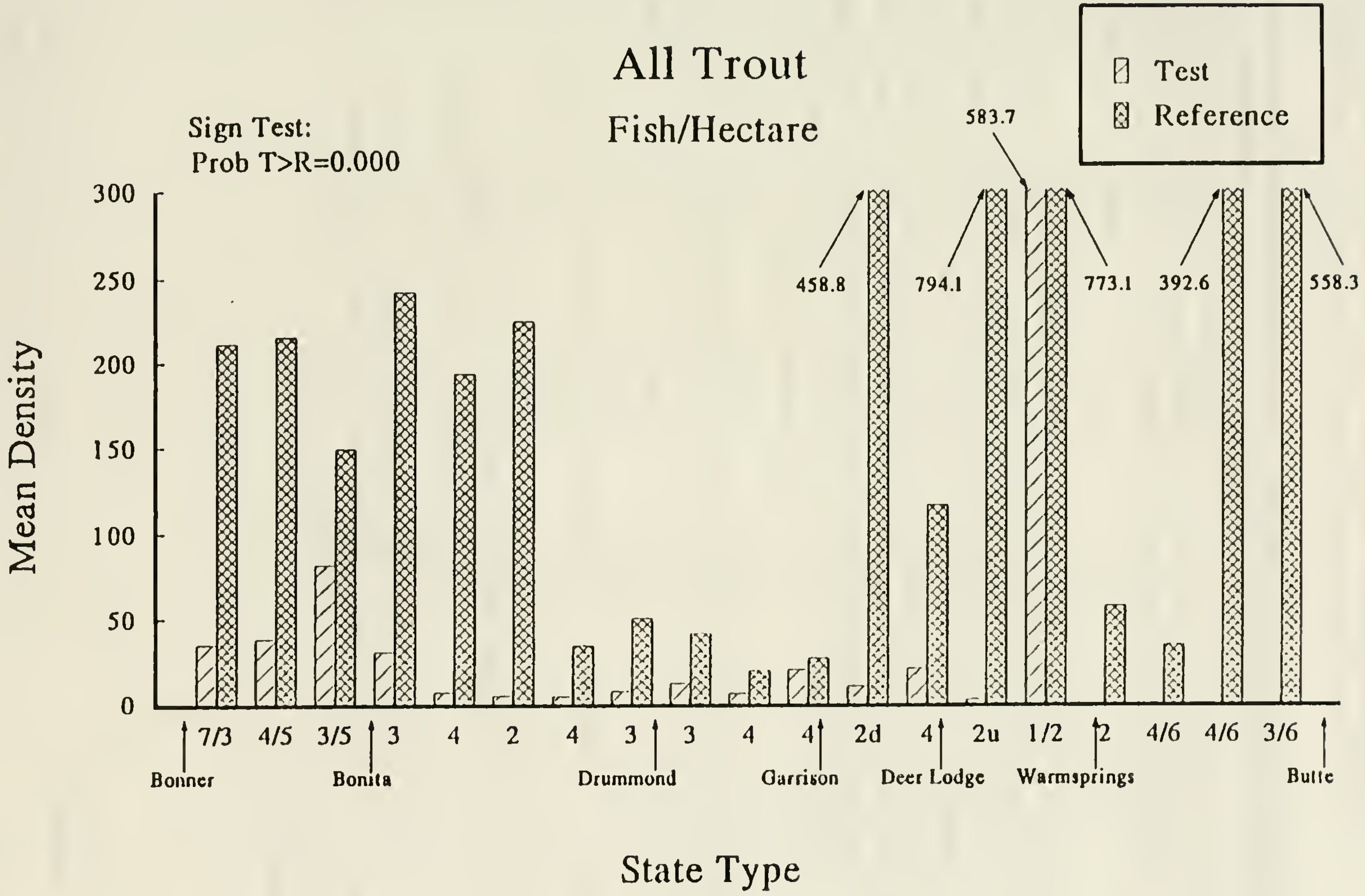

Figure 6-28. Mean Densities (trout/hectare) of All Trout in Test and Control (Reference) Sites in 1991. Source: Appendix G.

Table 6-27
Trout Density and Biomass: The Clark Fork River, Silver Bow Creek, and Matching Control (Reference) Streams in 1991

		Number/Ha		Weight/Ha	
Reach	State code	Test	Reference	Test	Reference
1	7/3	34.5	209.1[1]	8.8	41.6
1	4/5	38.0	214.8	14.0	46.6
1	3/5	81.9	148.1	27.5	28.1
2	3	29.9	240.8	6.3	53.3
2	4	6.5	192.0[1]	3.9	52.2
2	2/3	4.5	224.1	1.0	41.2
3	4	4.3	33.9	1.3	9.0
3	3	7.0	50.3	2.8	25.3
4	3	11.6	41.2	4.2	18.5
4	4	5.8	19.2	2.7	4.2
5	4	19.8	26.4	8.7	6.9
6	2d	10.1	458.8	4.1	126.1
6	4	20.6	116.3	4.1	22.3
6	2u	2.1	794.1	0.3	271.2
6	1/2	583.7	773.7	126.9	234.4
7	2	0.0	57.4	0.0	12.9
7	4/6	0.0	34.2	0.0	8.2
9	4/6	0.0	392.6	0.0	69.7
10	3/6	0.0	558.3	0.0	26.8

[1]Includes 1 bull charr.

Source: Appendix G.

severely altered by grazing; these severely grazed areas were selected to match Silver Bow Creek reaches severely altered by hazardous substances contained in streamside tailings deposits. The control sites thus represent a conservative baseline because trout densities at grazed reaches tend to be lower than in un-grazed stream areas (Platts, 1991).

In the Clark Fork River, trout density ranged from a low of 2 fish/hectare (approximately 5 miles downstream of the Warm Springs Ponds) to a high of 583 fish/hectare (immediately downstream of the Warm Springs Ponds) (Table 6-27). At the matching control reaches, trout density ranged from a low of 19 fish/hectare to a high of 794 fish/hectare. The ratio of mean trout density in the Clark Fork River reaches to the means at matching control reaches ranged from roughly 1:1.3 to 1:378.

When the population data were broken out by species, the same patterns were observed. Brown trout were significantly more abundant at control sites than in the Clark Fork River ($p < 0.001$) (Figure 6-29), and brown trout densities were greater in the control areas for 18 of the 19 site comparisons. Similarly, rainbow trout were significantly more abundant at control sites than in the Clark Fork River ($p < 0.001$) (Figure 6-30). In the Clark Fork River, rainbow trout were principally observed downstream of Rock Creek — as has been reported by numerous investigators. Rainbow trout densities were greater in the control areas for all 19 site comparisons. This absence of rainbow trout is consistent with their observed sensitivity to pulse toxicity and behavioral avoidance.

The results of this sampling confirm that the injuries described previously have caused significant reductions in trout populations in Silver Bow Creek and the Clark Fork River. Specifically:

- No trout (and virtually no fish of any species[26]) were observed in Silver Bow Creek.
- Trout populations in the Clark Fork River were consistently, and statistically significantly less than in similar control sites.
- Both brown and rainbow trout densities in the Clark Fork River were consistently, and statistically significantly less than in similar control sites.

[26] A single sucker was found in Silver Bow Creek.

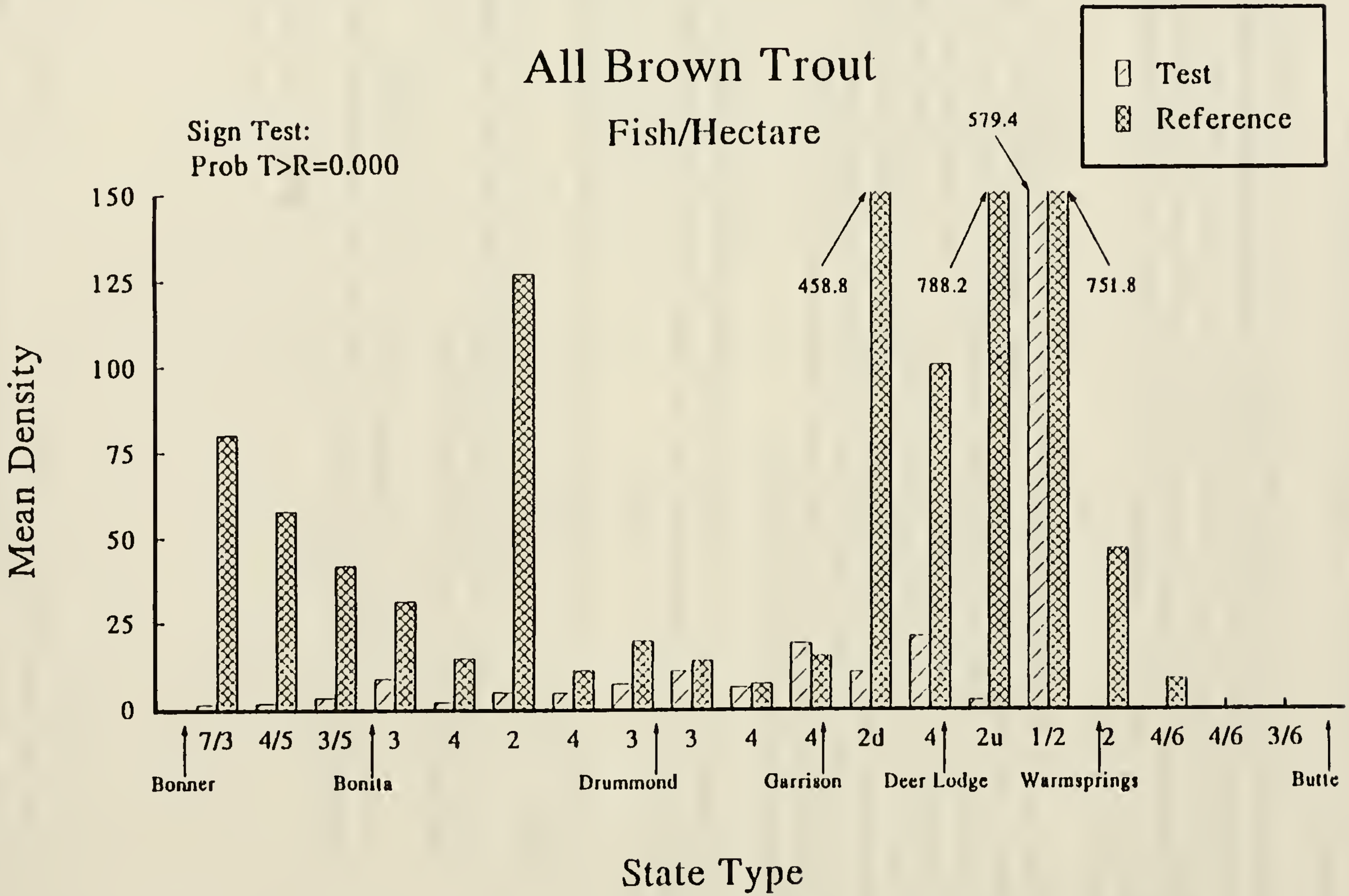

Figure 6-29. Mean Densities of All Brown Trout in Test and Control (Reference) Sites in 1991. Source: Appendix G.

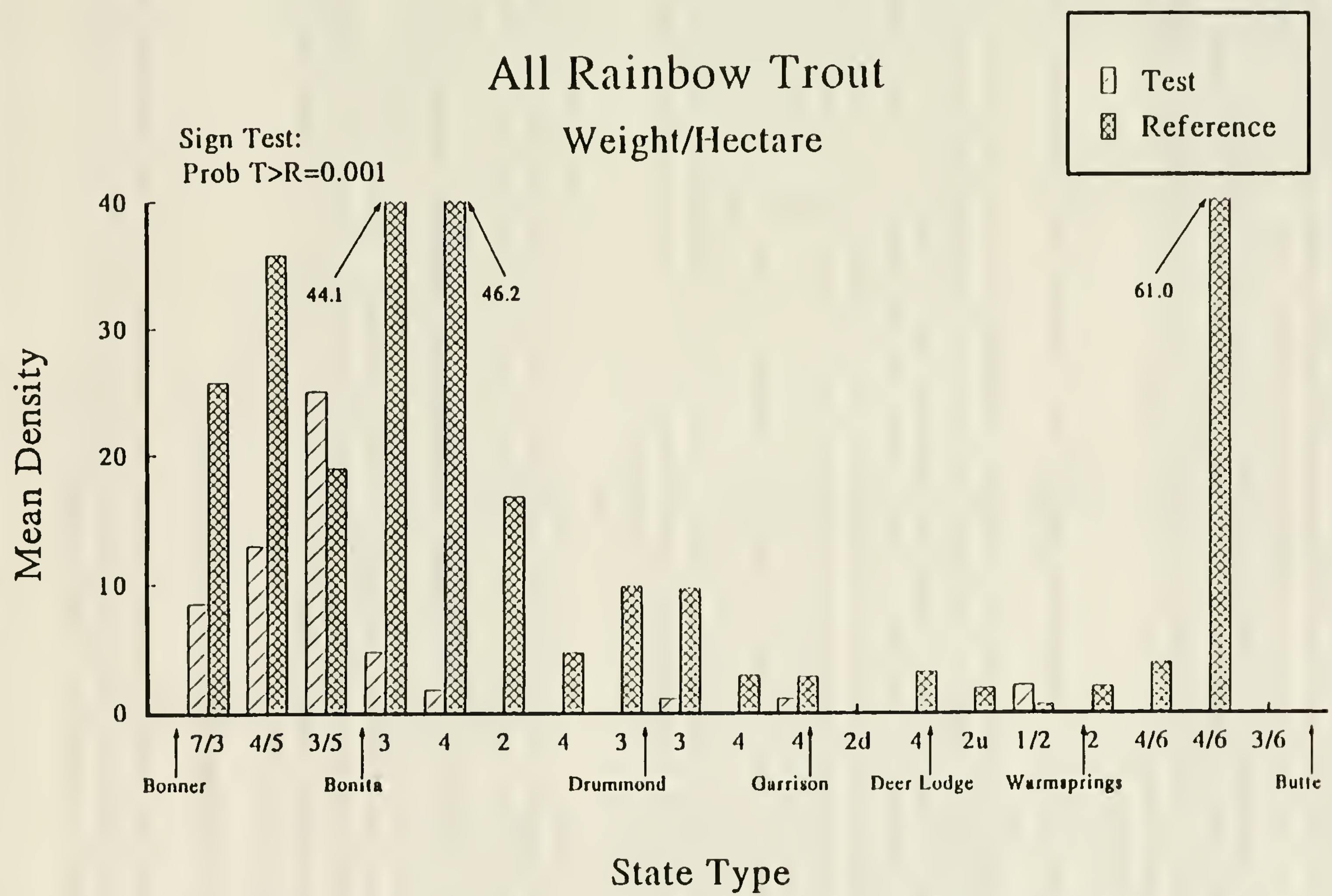

Figure 6-30. Mean Densities of All Rainbow Trout in Test and Control (Reference) Sites in 1991. Source: Appendix G.

Habitat-Normalized Population Data

When trout population data were adjusted for habitat and flow using the PHABSIM output (by dividing the number of trout by the amount of weighted usable area (WUA)), the same pattern was observed as with the unadjusted population data. Adult and juvenile brown trout densities were substantially lower in the Clark Fork River sites (Appendix G). Similarly, adult and juvenile rainbow trout densities were lower in the Clark Fork River sites (Appendix G). These adjustments demonstrate that the population differences observed between assessment and control sites were not a function of flow and habitat limitations in the assessment area.

Aggregated Habitat-Normalized Population Data: Baseline Trout Population Estimates

An aggregate estimate of total trout population reductions (brown and rainbow trout, juveniles and adults) was developed. As described in Appendix G, this aggregate estimate was developed by using the habitat normalized population data for each individual species/size class (e.g., brown trout adults/WUA) and projecting the total number of all trout that would be expected in Silver Bow Creek and the Clark Fork River under baseline conditions. Table Table 6-28 presents this aggregate population estimate in terms of the number of trout per hectare in the assessment area under current conditions (i.e., same data as presented for the assessment area sites in Table 6-27) and under baseline conditions. The values presented in Table 6-28 thus adjust the trout population injuries previously presented in Table 6-27 to account for habitat/flow differences between the injured and control sites. Overall, the values presented in 6-28 demonstrate the substantial degree to which trout populations have been reduced in Silver Bow Creek and the Clark Fork River.

Table 6-29 presents estimates of the total number of trout in Silver Bow Creek and the Clark Fork River under current and baseline conditions. These estimates were made by multiplying the number of trout per hectare in each reach/state type by the total number of hectares in that reach/state type to yield the total number of juvenile and adult trout of all species. These numbers are summed for all reach/state types sampled to approximate the total number of trout in the affected rivers. Current trout populations in Silver Bow Creek and the Clark Fork River were estimated to be 0 and roughly 28,000, respectively. When adjusted for habitat/flow, total trout populations in Silver Bow Creek and the Clark Fork River under baseline conditions were estimated to be on the order of 160,000. Thus, current trout densities have been reduced, overall, by a factor of approximately six.

Effects of Sampling Time: 1994 Sampling Data

Additional fish population sampling surveys were conducted in 1994 by resurveying the 14 sites on the Clark Fork River between Galen Bridge and Milltown Reservoir and their corresponding control sites that were sampled in 1991.

Table 6-28
Trout Population Densities (number of all trout/hectare) in Silver Bow Creek and the Clark Fork River Under Current Conditions and Projected Trout Population Densities Under Baseline Conditions

Reach	State Code	Current Trout Density (fish/ha)[1]	Baseline Trout Density (fish/ha)[1]
1	7/3	34.5	78.20
1	4/5	38.0	212.50
1	3/5	81.9	138.44
2	3	29.9	93.18
2	4	6.5	100.14
2	2/3	4.5	248.09
3	4	4.3	126.81
3	3	7.0	34.09
4	3	11.6	31.20
4	4	5.8	45.51
5	4	19.8	57.83
6	2d	10.1	988.06
6	4	20.6	215.14
6	2u	2.1	1,689.09
6	1/2	583.7	453.63
7	2	0.0	41.64
7	4/6	0.0	10.90
9	4/6	0.0	441.80
10	3/6	0.0	107.09

[1] Aggregated trout population densities are adjusted for habitat/flow (WUA) differences between impact and control sites.

Source: Appendix G.

Table 6-29
Baseline and Current Densities (fish/ha) and Total Numbers of Trout in the Clark Fork River and Silver Bow Creek

Reach	State	Total Area of State	Current Density (fish/ha)	Baseline Density (fish/ha)	Current Totals	Baseline Totals
1	8	31	—	—	—	—
1	7/3	24	35	78	842	1,908
1	4/5	37	38	213	1,388	7,761
1	3/5	68	82	138	5,546	9,371
2	4	32	7	100	208	3,202
2	3	10	30	93	287	895
2	4	130	7	100	846	13,025
2	2/3	12	5	248	55	3,037
2	4	18	7	100	114	1,762
3	4	29	4	127	124	3,653
3	3	4	7	34	25	121
4	3	85	12	31	990	2,662
4	4	3	6	46	16	125
4	3	10	12	31	120	323
4	4	11	6	46	66	515
5	4	49	20	58	974	2,844
6	2	12	10	988	116	11,393
6	4	9	21	215	189	1,977
6	3/4	21	21	215	441	4,605
6	2d	21	10	988	217	21,224

Table 6-29 (cont.)
Baseline and Current Densities (fish/ha) and Total Numbers of Trout in the Clark Fork River and Silver Bow Creek

Reach	State	Total Area of State	Current Density (fish/ha)	Baseline Density (fish/ha)	Current Totals	Baseline Totals
6	4	11	21	215	231	2,407
6	1/1	6	—	—	—	—
6	2	14	10	988	142	13,853
6	1/1	5	—	—	—	—
6	2u	23	2	1689	49	39,272
6	1/2	25	584	454	14,721	11,440
7	6	5	0	42	0	219
7	2	2	0	42	0	62
7	46	1	0	11	0	6
7	6	4	0	42	0	154
7	46	5	0	11	0	49
7	6	1	0	42	0	24
8	6	1	—	—	—	—
8	46	1	—	—	—	—
9	46	3	0	442	0	1,489
10	46	2	0	107	0	237
10	36	6	0	107	0	627
10	46	11	0	107	0	1,137
10	4	3	0	107	0	283
Totals[1]		700	40*	231*	27,705	161,662

— Denotes estimates of fish populations not available for reach/state type.

* Calculated as the sum of measured trout divided by the sum of measured hectares.

[1] Sum of individual values may not equal totals because of rounding.

Source: Appendix G.

The purposes of this additional sampling were:

1. To evaluate whether conclusions reached based on 1991 sampling data were supported by a second year of sampling data.

2. To evaluate whether time of sampling (within a summer) altered the overall conclusions of population decreases.

As in 1991, trout populations were counted in each designated stream section using direct underwater observation (snorkeling). Trout populations in 4 of the sites were sampled three or four times to evaluate if populations remained higher in control sites than in Clark Fork River sites throughout the summer.

The results of the 1994 sampling confirmed the conclusions drawn from the 1991 survey; control sites contained significantly more trout per hectare than corresponding sites of the Clark Fork River ($p < 0.0001$) (Figure 6-31). As in the 1991 survey, trout densities were higher in control sites than Clark Fork River sites for every site. The total trout density in 1994 for the test sites sampled ranged from 7 fish/hectare to 188 fish/hectare. Trout populations in control sites ranged from 39 fish/hectare to 528 fish/hectare. Densities of trout were higher generally in 1994 than in 1991 in both test and control sites (Figure 6-31). Both brown trout and rainbow trout were significantly more abundant at control sites than in the Clark Fork River ($p < 0.0009$).

Trout populations in select reaches were sampled multiple times throughout the summer of 1994 to evaluate whether time of sampling affected overall conclusions regarding trout population declines in the Clark Fork River. Results of these surveys indicate that time of sampling did not alter or bias the overall injury quantification conclusions: trout populations in the Clark Fork River reaches were consistently lower than at the matching control reaches, regardless of time of sampling (Figures 6-32 to 6-35).

Overall, the results of the 1994 sampling support the conclusion that temporal variability (annual and seasonal) did not bias or affect the overall conclusion that trout populations in the assessment area have been significantly and substantially reduced relative to baseline conditions.

6.5.4 Injury Quantification Summary

The results of injury quantification for fishery resources of Silver Bow Creek and the Clark Fork River clearly support the conclusion that trout populations have been significantly and substantially reduced relative to baseline conditions. Specifically, the data presented in this section support the following conclusions:

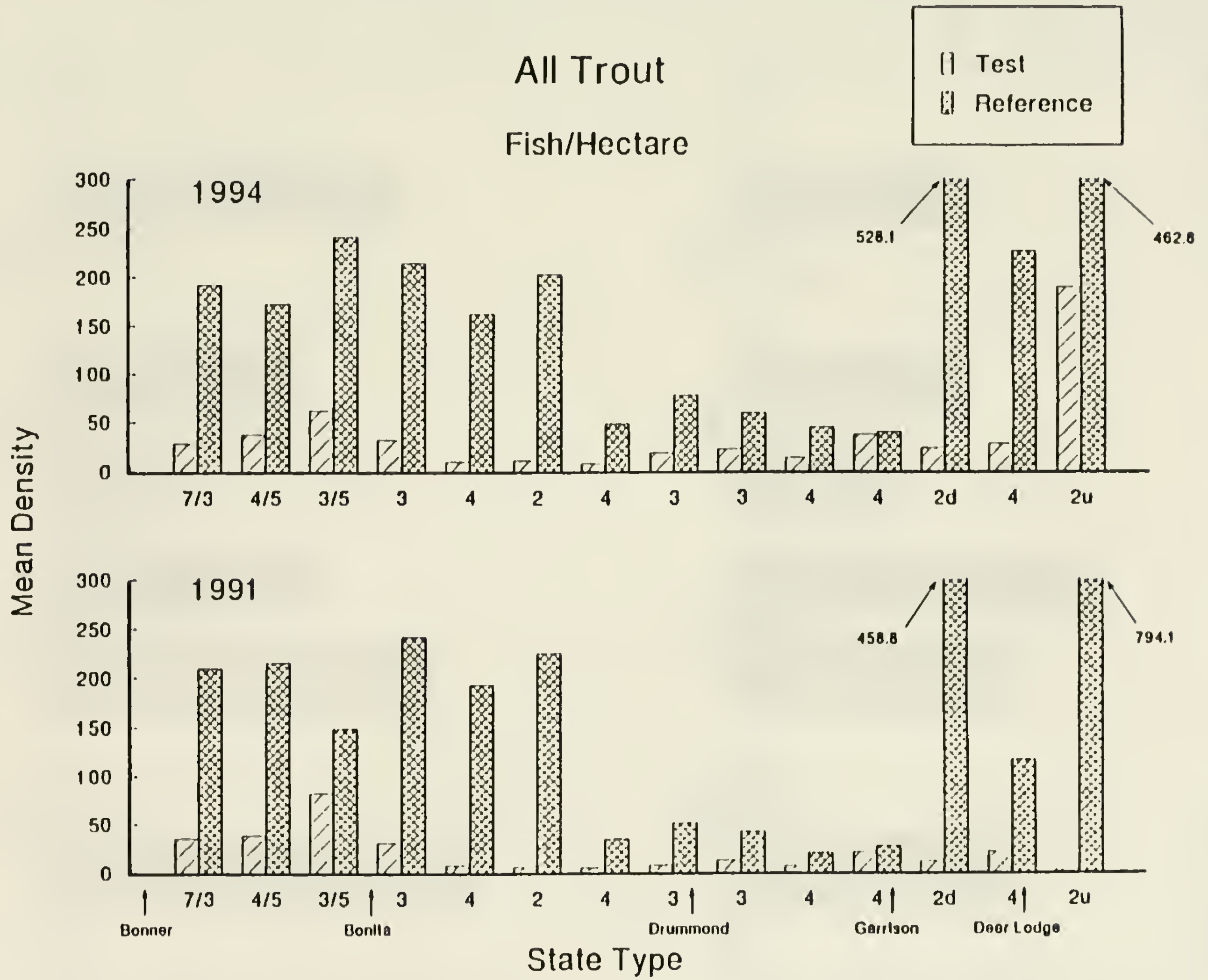

Figure 6-31. Mean Densities of All Trout in Test and Control (Reference) Sites in 1991 and 1994. Source: Appendix H.

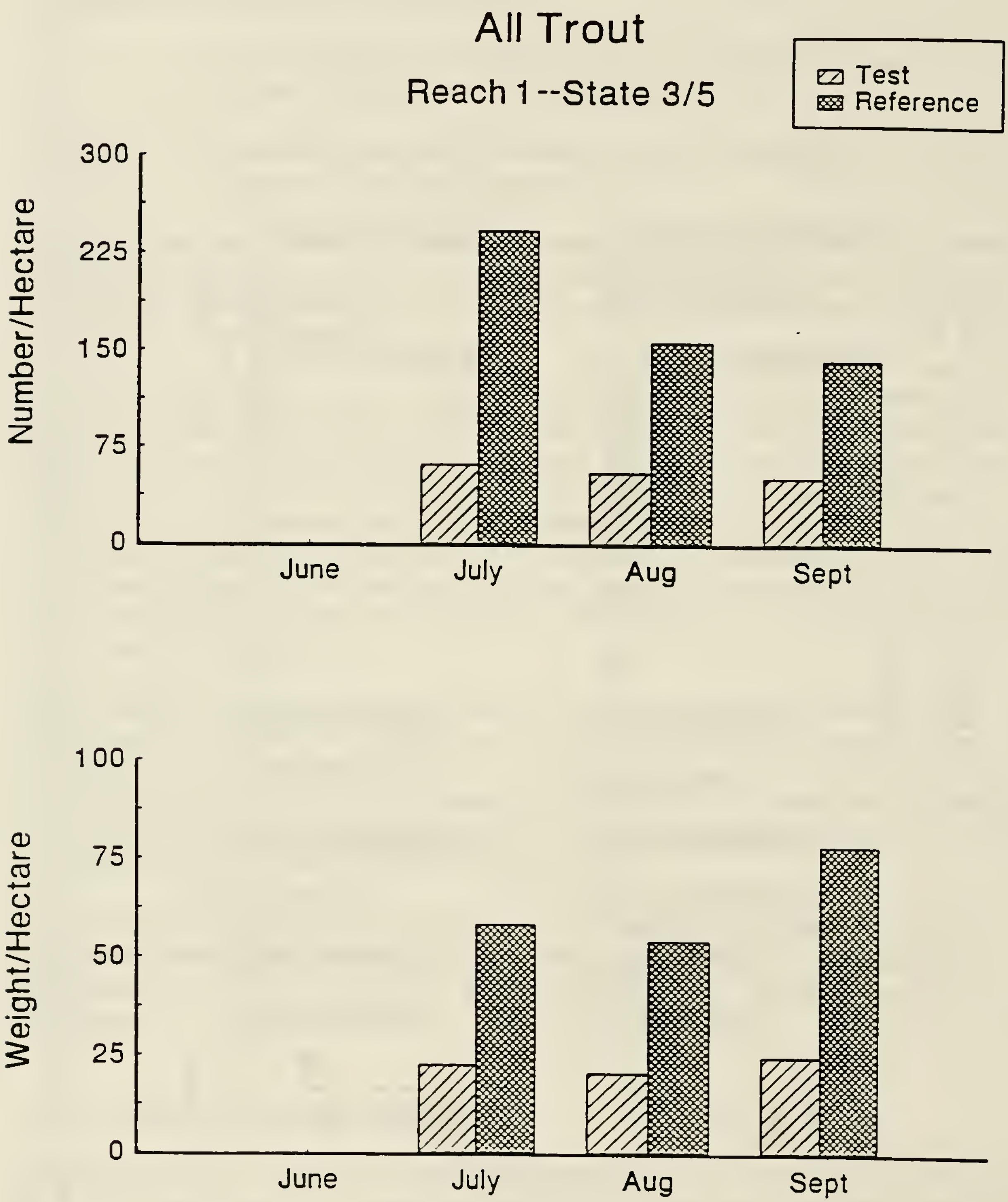

Figure 6-32. Mean Densities and Biomasses of All Trout in Reach 1 Test and Control (Reference) Sites in 1994. Source: Appendix H.

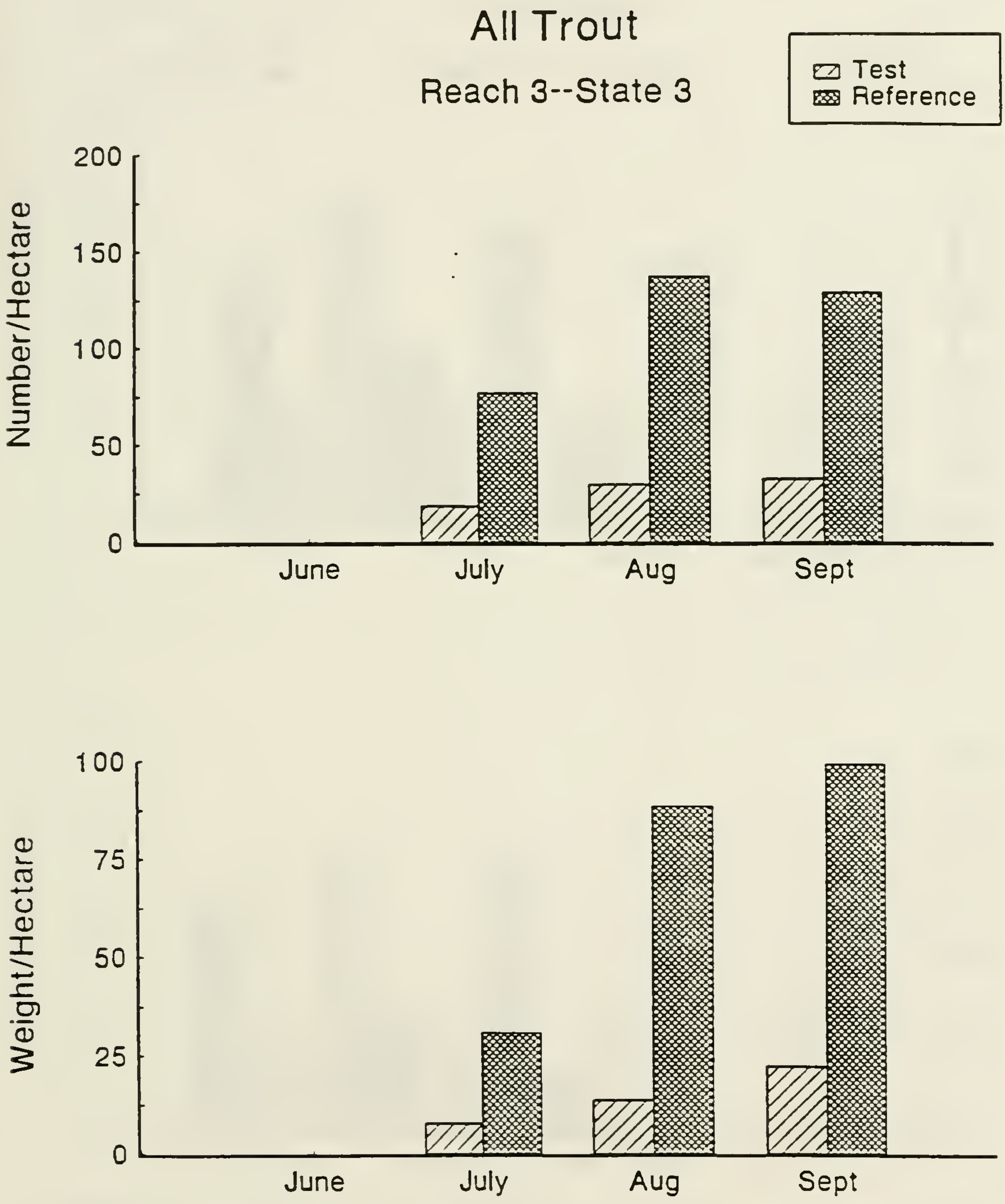

Figure 6-33. Mean Densities and Biomasses of All Trout in Reach 3 Test and Control (Reference) Sites in 1994. Source: Appendix H.

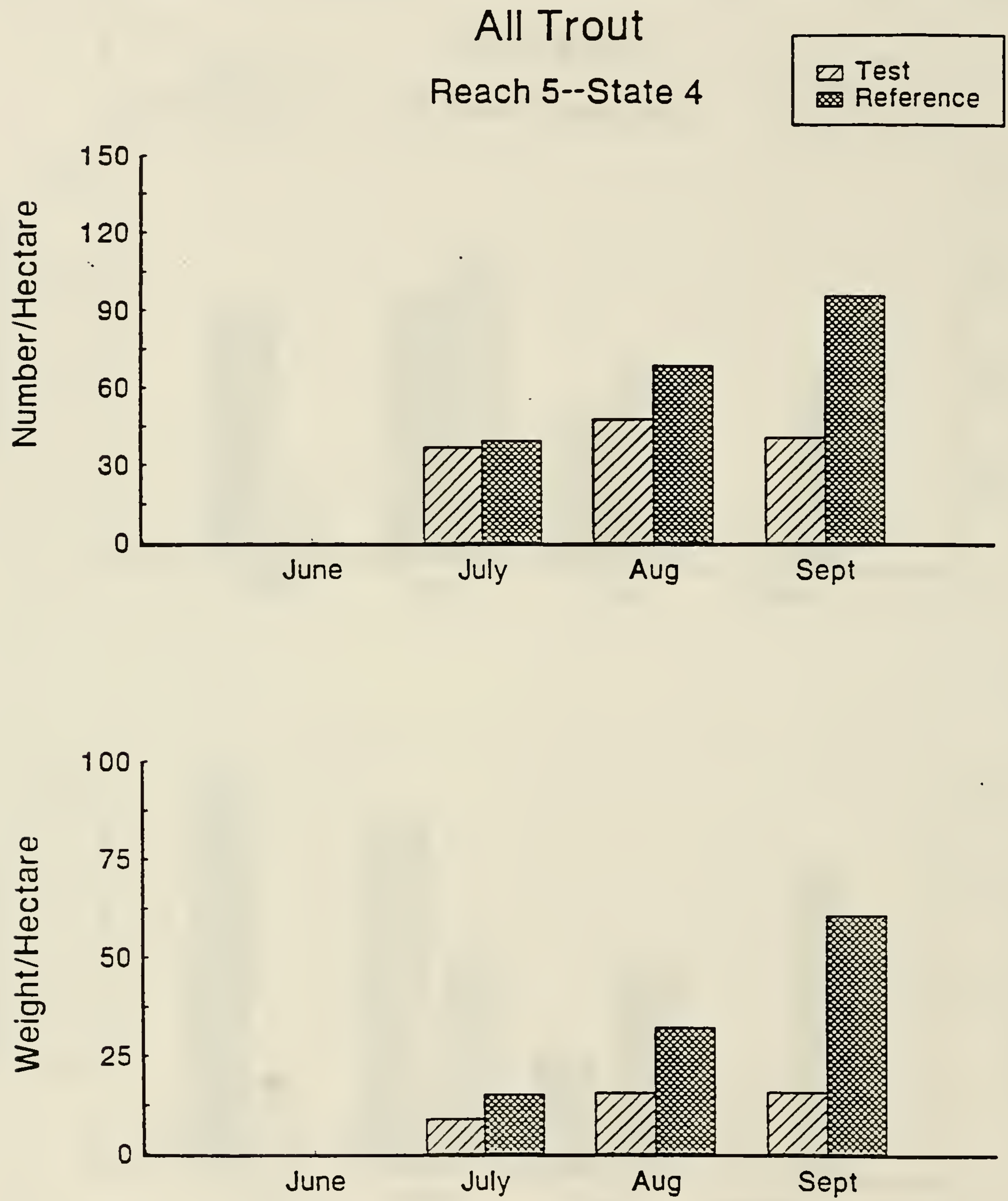

Figure 6-34. Mean Densities and Biomasses of All Trout in Reach 5 Test and Control (Reference) Sites in 1994. Source: Appendix H.

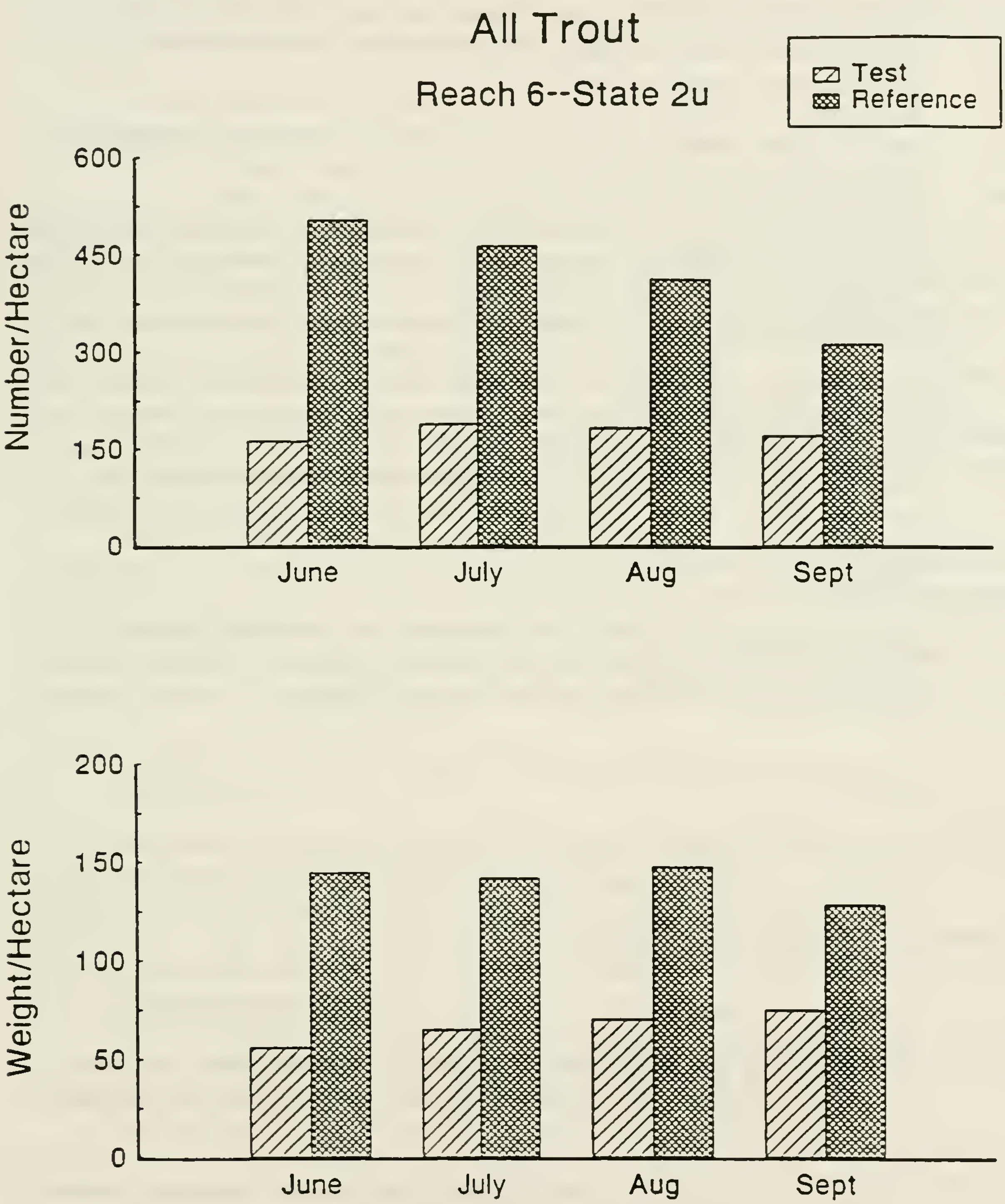

Figure 6-35. Mean Densities and Biomasses of All Trout in Reach 6 Test and Control (Reference) Sites in 1994. Source: Appendix H.

- Control sites for fisheries population measurements were selected using an objective, hierarchical classification approach that minimized differences between rivers. Overall, the control sites were similar to sites in the assessment area in terms of geology, geomorphology, hydrology, substrate type, and general habitat conditions. Water quality conditions between control and impact sites generally were similar. The Clark Fork River reaches tended to have somewhat higher levels of hardness, conductivity, alkalinity, and nitrate/nitrogen. However, these water quality parameters are correlated with increased trout populations. Therefore, the control site selection was conservative; trout populations in the assessment area would be expected to be somewhat higher than at control sites — the reverse was found to be the case.

- No trout (and virtually no fish of any species) exist in Silver Bow Creek despite the availability of habitat. By contrast, Silver Bow Creek baseline conditions supported populations of rainbow trout, brown trout, and brook trout. Moreover, the baseline population estimate is conservative because control sites were severely altered by grazing to match the habitat degradation in Silver Bow Creek caused by streamside tailings containing hazardous substances.

- Trout populations were statistically significantly and substantially reduced relative to baseline conditions. Overall, trout populations in Silver Bow Creek and the Clark Fork River are about one-sixth of baseline.

- Both brown trout and rainbow trout were significantly more abundant at control sites.

- Rainbow trout largely are absent from the Clark Fork River upstream of its confluence with Rock Creek. This observation is consistent with the sensitivity of rainbow trout to acute pulse toxicity and to behavioral avoidance, as shown in injury determination sections.

- Sampling performed in 1994 demonstrated similar results as sampling performed in 1991. Although the absolute number of trout varied across sampling years, the relative difference between Clark Fork River and control sites did not. In addition, sampling performed throughout the summer period demonstrated that the time of sampling did not bias the overall conclusions.

Overall, the conclusion to be drawn from the injury quantification phase is that the injuries that have resulted from exposures to hazardous substances released from Butte and Anaconda have resulted in the total elimination of trout from Silver Bow Creek, substantial reductions in the number of trout present in the Clark Fork River, and reductions in the diversity of trout

species in Silver Bow Creek and the Clark Fork River. These population reductions represent a single harm caused by multiple exposures to hazardous substances.

6.6 RESOURCE RECOVERABILITY

This section discusses recovery of fish populations from current injured conditions. As was described in previous sections of this chapter, injuries to fishery resources are caused by both surface water and food-chain exposures. Surface water contamination with hazardous substances is a function of exposure to contaminated bed, bank, and floodplain sediments, as well as to releases from surface deposits and contaminated groundwater (see Chapter 4.0). Food-chain contamination is a function of exposure to contaminated surface water, bed sediments, and periphyton (see Chapter 5.0). In order for fishery resources to be restored, both of these exposure pathways — surface water and food-chain — must be restored. Moreover, recovery of trout populations to baseline levels will not be immediate following restoration of surface water and food-chain exposures; population recovery will occur over some substantial time period following restoration.

As described in Chapters 4.0 and 5.0, planned remedial activities are not anticipated to restore surface water, bed sediments, or benthic macroinvertebrates. Therefore, these activities will not restore trout populations to baseline conditions. Any further natural recovery of trout populations will lag behind natural recovery of surface water, sediments, and benthic macroinvertebrates — a recovery period expected to last hundreds, if not thousands, of years.

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